

DTIC QUALITY IMPROVEMENT

REMEDICATION OF LEAD CONTAMINATED SOIL
AT
GREENBURY POINT
ANNAPOLIS, MD

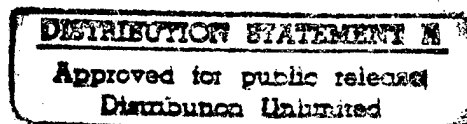
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*In Partial Fulfillment of the Requirements for the Degree of
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FOREWORD

The Navy approaches protection of the environment in this manner:

The Navy's ability to accomplish its mission requires daily operations in the land, sea, and air environment. The Navy is committed to operating in a manner compatible with the environment. National defense and environmental protection are, and must be, compatible goals... an important part of the Navy's mission is to prevent pollution, protect the environment, and protect natural, historic, and cultural resources. (DoN, 1994)

The Navy as a whole has moved toward proactive environmental conservation, compliance, and cleanup. Although levels of lead contamination on Greenbury Point may not be considered "life-threatening" compared to other contaminated sites, the Navy is committed to remediating past contamination for which it is responsible in as timely a manner as possible, no matter what the level. The Naval Academy is especially interested in Greenbury Point's remediation, not only because of current and future use of Greenbury Point, but because they have built an exemplary reputation on environmental compliance.

Study of the remediation of lead contaminated soil at Greenbury Point provides me a perfect opportunity for research in the University of Maryland Civil Engineering graduate program. Not only does research of this problem allow me to pursue a topic in which I am interested, but it allows me to serve the Navy's interests as well. Because the Navy is funding my education, a research topic which will benefit the Navy is mutually advantageous. Having served as the Environmental Officer at the U.S. Naval Academy for three years, finding a means of funding a study to determine an appropriate cleanup

method was a problem I faced. Providing a solution the Navy can use is a personally and professionally fulfilling undertaking.

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EXECUTIVE SUMMARY

Greenbury Point is a parcel of land located across the Severn River from the U.S. Naval Academy and owned by the U.S. Navy. High levels of lead have been found in the soil of the 231 acre tract of land, and the most probable cause is leaching, chipping, and flaking of lead paint from the sixteen antenna towers which are housed on the facility.

The Navy is required to remediate Greenbury Point under the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). In order to satisfy the Remedial Investigation/Feasibility Study portion of the CERCLA process, information collection and analyzation are conducted.

The remedial investigation is satisfied through compilation of information required to adequately characterize Greenbury Point. Information includes data on lead, applicable regulatory requirements, soils types, contamination, site maps, field investigations, utility drawings, history, archeology, and natural resources.

The feasibility study is satisfied through examination of remedial options. Various treatment technologies are screened for effectiveness in reducing the lead contamination or risks associated with the lead contamination. These include in-situ technologies, such as containment, soil flushing, and electrokinetic treatment; ex-situ technologies, such as physical separation/concentration, soil washing and pyrometallurgical separation; and technologies with both in- and ex-situ applications, such as cement based solidification/stabilization, polymer microencapsulation solidification/stabilization, and vitrification. Each of these technologies is described and compared to conditions at Greenbury Point.

The number of technologies requiring further consideration was reduced from ten to three: physical separation/concentration; soil washing; and cement based solidification/stabilization. These options are fairly well established, effective against lead, and compatible with site conditions at Greenbury Point. Because they are fairly well established, these technologies are available from commercial vendors at a reasonable cost.

However, more extensive data is required before a final determination can be made. Approximately five parameters for each are required. The most important for all three is depth and extent of contamination. Each also requires information on various soil characteristics, such as soil particle size distribution, specific gravity, sulfate content, and organic content. A suitable extraction fluid must also be investigated for soil washing.

Subsequent further analysis using this data can be combined with the results of this investigation to complete the Remedial Investigation/Feasibility Study portion of the CERCLA process for Greenbury Point.

INTRODUCTION

The United States Department of the Navy has discovered high levels of lead in soil at Greenbury Point, which is located across the Severn River from the United States Naval Academy (USNA) in Annapolis, MD. The land was previously occupied by a Navy command known as the Naval Radio Transmitting Facility (NRTF), which housed a large array of antenna towers for the purpose of submarine communications. NRTF was closed by the Base Closure and Realignment Commission in 1993, and the land was subsequently turned over to the United States Naval Academy. Transmitting operations at NRTF ceased in January 1996, and the antenna towers are planned for removal. The Naval Academy plans on using the land for conservation and to educate the public on the area's rich history and natural resources.

Past preservation methods for the antennas at NRTF resulted in high levels of lead in the soil. Removal of lead contamination from Greenbury Point was placed on the Navy's Installation Restoration Program. Facilities placed on this program are required to remediate lands according to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Thus, a federal requirement exists mandating the cleanup of this tract of land, and the Naval Academy possesses a duty to do so. The problem is compounded by the existence of a copper grounding system which lies 6 to 10 inches below the soil's surface in the area of the antenna array. Any remediation operations will have to avoid damaging the system, as the Navy may choose to leave the towers in place in case they are needed in the future. The Naval Academy is especially anxious to pursue the cleanup of the soil because of their future plans for the

area. Lead in the soil must be reduced to a level rendered safe for human health, as school groups and children, among others, will use the area to learn about nature and their environment. However, due to budget constraints and more pressing cleanup priorities in the Navy, little funding has been allotted to dedicate towards the cleanup.

SECTION 1: REGULATIONS

1.1 General:

Remediation of the contaminated soil on Greenbury Point was placed on the Navy's Installation Restoration Program in 1994. This means that the site is to be cleaned up under the provisions of CERCLA, or the Comprehensive Environmental Response, Compensation, and Liability Act.

CERCLA was passed in 1980 for the purpose of providing a legal and regulatory basis to clean up past releases of hazardous substances. It was later amended by the Superfund Amendment and Reauthorization Act of 1986 (SARA). CERCLA imposes strict liability for cleanup costs upon generators, transporters, and owners responsible for releases of contamination. The law covers three general areas:

- The identification, analysis, and remediation of releases of contamination;
- The rules of liability associated with the remediation of these releases; and
- The general reporting requirements.

This paper covers the first general area of CERCLA, the remediation process. Moneys for cleanups are provided from revenues generated under the Superfund Tax Act, a companion piece of legislation to CERCLA. The Navy and other Department of Defense (DoD) installations are eligible for funds under the Defense Environmental Restoration Account (DERA). DoD prioritizes contaminated sites for receipt of DERA funding; Greenbury Point has received a low priority for funding for several reasons:

- Greenbury Point possesses low levels of contamination compared to other DoD installations;
- The majority of Greenbury Point is currently used as wildlife management area; thus relatively infrequent human exposure exists; and
- The current threat to human health and the environment is minimal.

However, the Naval Academy views a substantial need to remediate the Point due to planned use, which is discussed in Section 2.1.6.

The CERCLA remediation process is lengthy. The following is a listing of the steps in the process: site discovery; preliminary assessment; site inspection; hazard ranking analysis; placement on National Priorities List (NPL) if applicable; remedial investigation/feasibility study; remedy selection/record of decision; remedial design; remedial action; and project closeout. This paper will cover portions of the Remedial Investigation and the Feasibility Study. Figure 1.1 is a flow chart of the order in which portions of the Remedial Investigation/Feasibility Study process should be satisfied.

1.2 Remedial Investigation:

The purpose of the Remedial Investigation (RI) is to collect data to adequately characterize the site. This data allows the development and evaluation of effective remedial alternatives. Information on the risks of the site to the public and to the environment are delineated, and the nature and character of the contamination are determined. The RI is composed of three parts:

- Scoping of the Remedial Investigation/Feasibility Study;
- Site characterization; and

- Treatability investigations.

The scoping process for Greenbury Point is covered under Section 2. Existing information is evaluated to determine the extent to which additional data must be collected. Data on soils, aerial photographs, and geological data may be collected. Operable units are also identified for evaluation. An operable unit may be soils, groundwater, or air emissions; the purpose of identification of an operable unit is to concentrate on manageable areas and to reduce the complexity of the RI.

The site characterization step is covered under Section 3. Site characterization involves conducting field investigations and defining the nature and extent of contamination. Information on waste types, concentrations, and distributions is collected. Applicable or relevant and appropriate requirements (ARARs) are also determined. These are regulatory requirements which apply to the particular cleanup, such as maximum contaminant levels (MCLs). MCLs are limits set on the maximum amount of contaminant allowed in a particular media, whether it be soil, water, or air. Levels below these limits are considered safe for human health and the environment. If no ARAR exists, risk analysis is used to develop appropriate cleanup levels.

Treatability investigations are not covered in this paper. These investigations occur after a portion of the Feasibility Study has been conducted. They involve bench or pilot scale tests of remediation alternatives selected for further evaluation in the Feasibility Study.

1.3 Feasibility Study:

The Feasibility Study (FS) evaluates various cleanup alternatives for effectiveness in reducing or eliminating the contamination or risks associated with the contamination. The

purpose of the FS is to develop a series of alternative remedies so that the decision maker, ultimately EPA, can determine which remedy will be used for remediation. Development of cleanup options is integrated with site characterization work. The FS is composed of two parts:

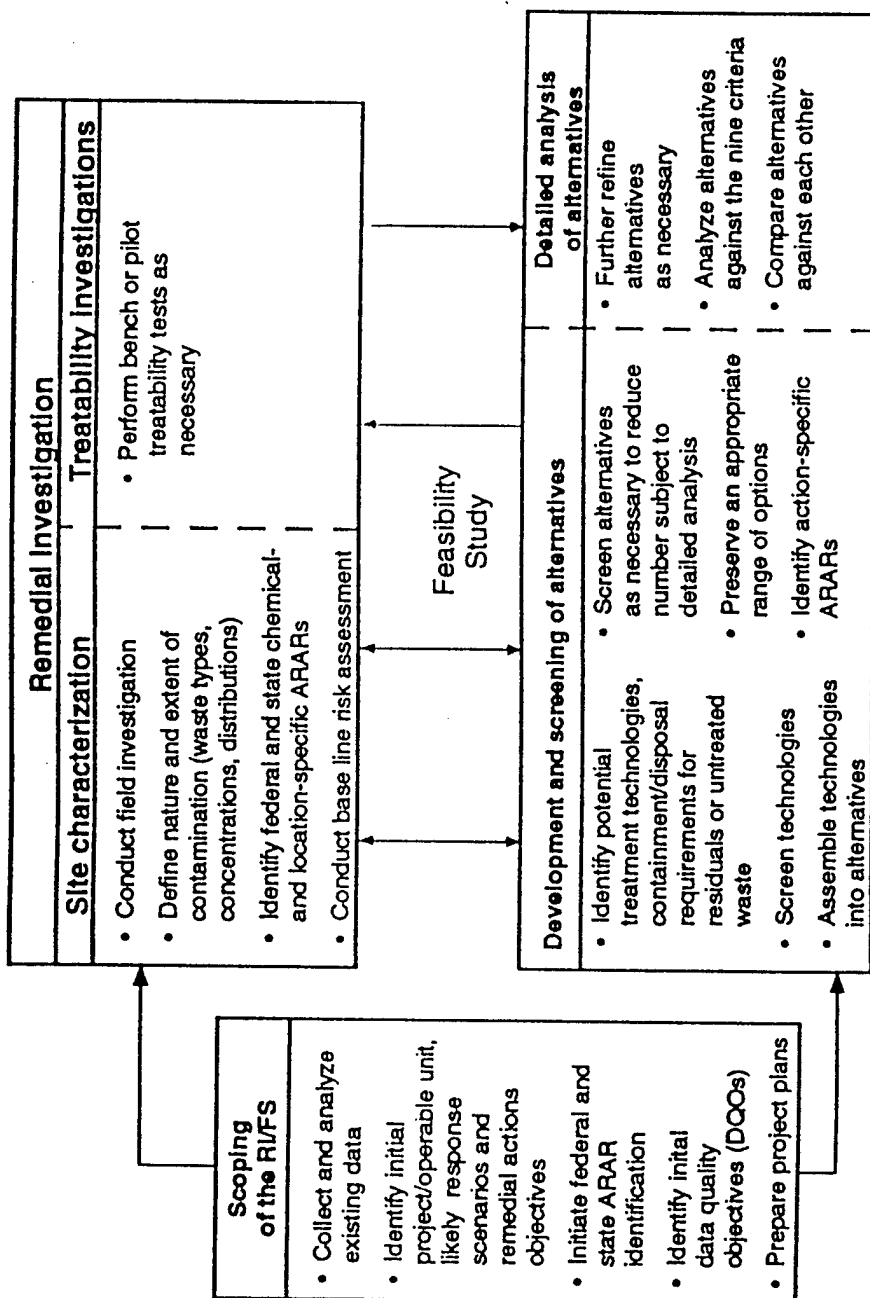
- Development and screening of alternatives; and
- Detailed analysis of alternatives.

Development and screening of alternatives is covered under Section 4. Potential treatment technologies are identified and assembled into alternatives. They are then screened as necessary to reduce the number to a manageable level for detailed analysis. Any action-specific ARARs that may exist are determined. It must be noted that although cost is an element, it is a very minor consideration in selection of alternatives for further analysis. Effectiveness and reduction of threat to health and the environment are the ultimate factors in selection.

A detailed analysis of the alternatives is not performed in this study. This study satisfies portions of the process to the point at which remediation alternatives requiring further analysis are identified.

Figure 1.1.1
Flowchart of RI/FS

(Bedient et al., 1990)



SECTION 2: REMEDIAL INVESTIGATION: SCOPING

2.1 Greenbury Point:

2.1.1 Description of Problem:

The operable unit in this study is surface soil on Greenbury Point. The soil around the antennas at Greenbury Point contains lead. Lead-based paint was historically used on the antenna towers until 1978, when its use was banned by the U.S. Consumer Product Safety Commission. Soil testing around the bases of the towers and in residential areas has indicated elevated lead levels. Eighty-one samples from around the sixteen antennas on Greenbury Point were taken, and the soil around seven of the antennas contains high concentrations of lead. Additional testing was performed in residential areas, and the soil around one of the housing units showed high levels.

The source of lead in the soil is the paint from the antenna towers. Lead based paint was used on the towers from 1918 to 1978. A variety of processes have caused the paint to ultimately end up in the soil. Natural weathering has caused the paint to chip and settle to the ground. Acid rain could also be a source for leaching of the lead from the paint down the towers and into the ground. Maintenance of the towers has also been continually performed. These maintenance operations include chipping and stripping built-up layers of paint, which has resulted in lead paint particles of various sizes to settle to the ground. Unfortunately, no detailed information exists confirming frequencies, dates, and duration of these operations.

Figure 2.1



LOCATION OF GREENBURY POINT

(Ecology and Environment, 1996)

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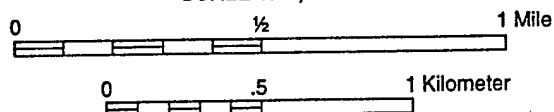
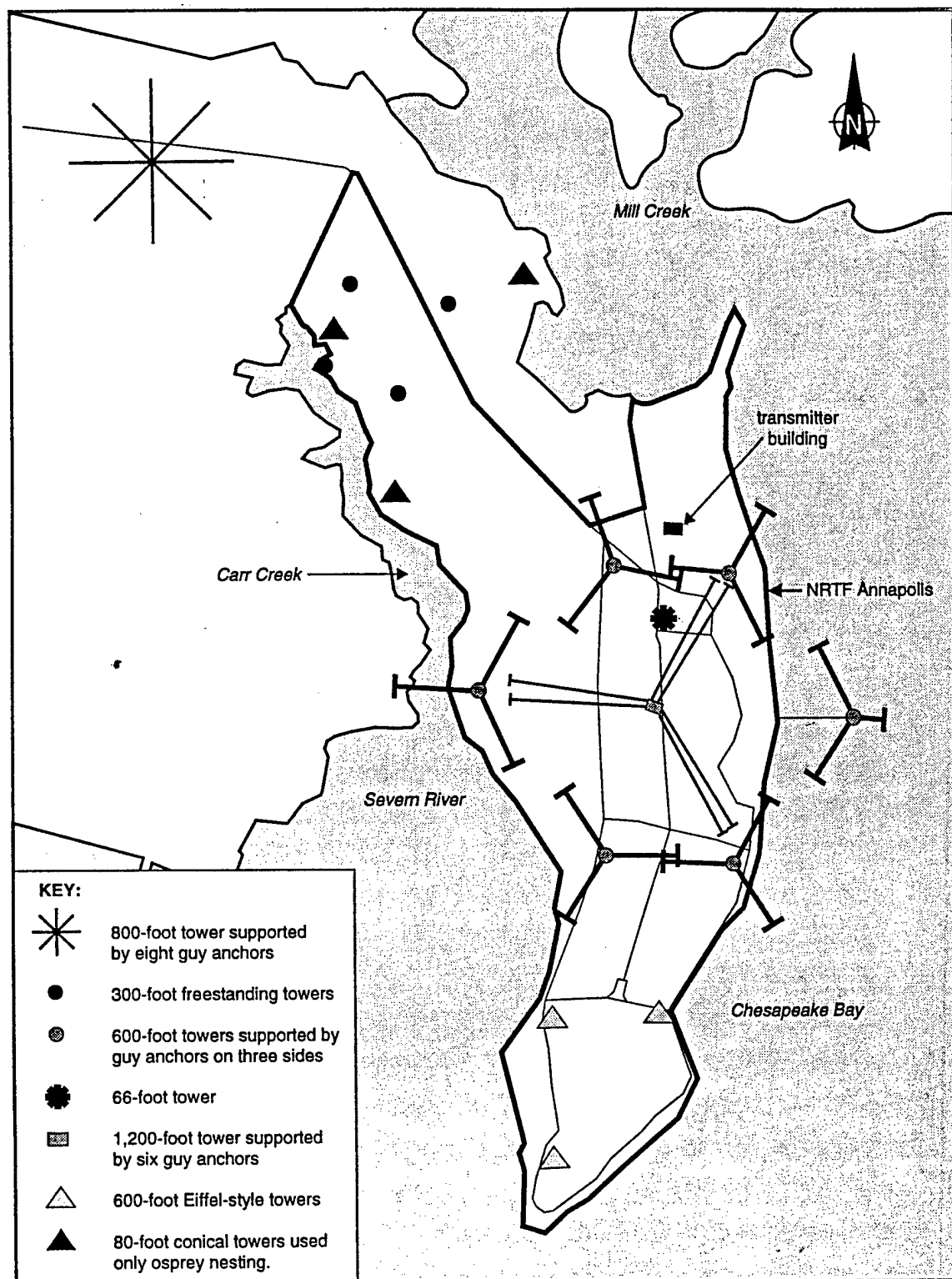
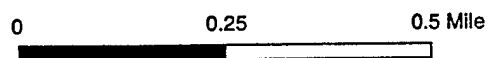


Figure 2.2



SOURCE: Ecology and Environment, Inc. 1996

SCALE



TYPE AND LOCATION OF ANTENNA TOWERS, NRTF ANNAPOLIS

2.1.2 Site Description:

Greenbury Point is a tract of land located across the Severn River from the Naval Academy. The Point is approximately 231 acres and is located on a peninsula that protrudes into the Chesapeake Bay. Carr Creek, Naval Station Annapolis, and the Severn River are west and southwest of the property, and the Chesapeake Bay and Mill Creek are east and southeast of the property. The U.S. Naval Academy Golf Course is north of Greenbury Point. Figure 2.1 contains a map of the location of Greenbury Point.

The NRTF Annapolis, which transmitted low frequency (LF) and very low frequency (VLF) communications since the 1940's was closed by the Defense Base Closure and Realignment Commission in 1993. The property has been transferred to the U.S. Naval Academy for conservation purposes, and transmitting operations ceased in January 1996.

Sixteen antenna towers are located on Greenbury Point, and three others are located on the nearby U.S. Naval Academy Golf Course and off a causeway into the Chesapeake Bay. The antenna towers located on Greenbury Point may be removed in the future because they are no longer of service to the Navy. As a result of the closure of NRTF, tower maintenance will not be funded after the year 2000. Safety and liability concerns have precipitated the proposed removal of the towers. The primary safety concern is associated with the aircraft which rely on the antenna lights to indicate the location of the towers. However, the towers may be left in place in order to serve future military needs or for rental purposes (Arnoldi, 1997). The total of nineteen towers are connected by halyards and comprise the NRTF antenna array. Figure 2.2 contains a map

of antenna locations. The towers range in height from 66 feet to 1200 feet with various configurations. Eleven towers are freestanding, with concrete foundations under each leg. The eight remaining towers are supported by a concrete base and guy wires anchored into the ground. Six of the anchors extend beyond the property into the Chesapeake Bay near the confluence of Mill Creek. One of the towers, the Low Frequency "Marconi Triatic antenna", is considered eligible for listing on the National Register of Historic Places. In addition, the three 80 foot conical towers are used solely for osprey nesting. A radial grounding system is buried 6 to 12 inches underground that mirrors the outline of the antenna array.

The history, archeology, natural resources, and planned use for Greenbury Point are important factors in determining appropriate remediation methods. Data on these parameters was collected for the scoping process and can be found in Appendix A.

2.2 Lead:

2.2.1 Introduction:

Lead, represented by the chemical symbol Pb, is one of the most commonly used metals in the United States today. Among the nonferrous metals, only aluminum, copper, and zinc are presently used in greater quantities than lead. Lead has been used in the production of various consumer and commercial items, including automobile batteries, other types of batteries, equipment, paints, crystal, and in gasoline additives (Paff and Bosilovich, 1995).

Until the early 1980s, gasoline additives accounted for the second largest use of lead produced in the United States behind storage batteries (Paff and Bosilovich, 1995). The estimated consumption of lead in 1992 was 1,2220,000 metric tons (EPA, 1995). Use of lead peaked to about 250,000 tons per year in the mid 1970s. However, annual use has declined rapidly since the 1970s, when phasing out lead gasoline was initiated (Page and Chang, 1993). Although present use is now estimated to be less than 20,000 tons per year, past use has already resulted in widespread contamination of surface soils (Page and Chang, 1993).

2.2.2 Properties and Forms of Lead:

Lead's properties are responsible for its wide use. The metal is very soft and malleable and possesses a density of 11.35 g/cm^3 . It also has a relatively low melting point of 327.4 degrees Celcius (C). Because of these qualities, the metal can be easily cast, rolled, and extruded. In addition, lead exhibits a silvery, gray, or bluish-white color when freshly cut, but tarnishes when exposed to air (EPA, 1995).

Lead sources in soils, which have originated from human activities, typically include acetates, organometallic compounds, lead oxides and hydroxides, elemental lead, lead-metal oxy-anion complexes, sulfates, halides, sulfides, and silicates. (Paff and Bosilovich, 1993; EPA, 1995) The most common oxidation states for lead are 0 and +II. Stable complexes are formed from lead and ligands present in soils and aquatic systems. Inorganic ligands include Cl^- and CO_3^{2-} , while organic complexes are formed from humic and fulvic acid organic ligands. Low-solubility compounds are also formed when soluble lead reacts with carbonates, sulfides, sulfates, and phosphates. Lead carbonate is also formed at pH values greater than 6. Lead precipitates to form PbS when high concentrations of sulfide are present. PbS, or galena, is naturally present in the environment in small amounts. PbS is also the most stable solid in reduced conditions with sulfur. However, when exposed to air, the sulfur is oxidized to sulfate, and PbS is converted to oxides, carbonates, sulfates, and sulfosalts. Stable lead phosphates and lead phosphate chlorides also form when phosphate is present (Paff and Bosilovich, 1993; EPA, 1995).

2.2.3 Transport of Lead:

The mobility of metals in soil is of particular concern, as the potential of transfer from the soil is likely through two routes:

- through the soil down to the groundwater aquifer
- via plant root uptake, termed "bioavailability"

Processes such as adsorption, ion exchange, precipitation, and complexation affect the fate of lead in soil. Once released into the soil, most of the lead remains there; lead is

fairly immobile in soil, and very little is normally transported to surface water or groundwater. Lead may form insoluble organic lead complexes in soils with a high organic content if pH is in the range of 6 to 8. Hydrous lead oxide complexes and lead carbonate or lead phosphate precipitates form under the same conditions if less organic matter is present. If the pH drops to below 6 to around 4, the organic lead complexes become more soluble and have an increased capability to leach out. At the soil surface, lead may be converted to lead sulfate, which is more soluble than lead carbonates or lead phosphates. Therefore, possibility of leaching is increased at the surface (EPA, 1995).

Although lead has been demonstrated to be fairly immobile and unavailable for plant root uptake, it is of concern due to deposition on plant tissue surfaces (Mench et al., 1994). This has a direct effect on the food chain. However, lead contamination has not been found to spread through the transport of lead by aquatic and terrestrial organisms to areas other than those contaminated. Because lead is chemically immobile in soils, lead deposited on the soil surface will remain until it is physically removed by erosion or man (Page and Chang, 1993).

2.2.4 Levels of Lead - Applicable or Relevant and Appropriate Requirements:

Lead, of course, is naturally present in the environment. However, high quantities of lead are detrimental to the health and well being of humans. But what quantities of lead are acceptable without being a threat to life? Acceptable levels of lead vary depending on the medium in which it resides. While quantifiable numbers exist for air and water, no consensus exists on an acceptable level of lead in the soil.

Federal regulations determine the acceptable levels of lead in the air and water. Levels of lead in the atmosphere are regulated by the Clean Air Act. The EPA requires that the concentration of lead in air that the public breathes shall not exceed $1.5 \mu\text{g}/\text{m}^3$ averaged over three months. EPA now regulates the limit of level of lead in leaded gasoline to 0.1 gram per gallon and the level of lead in unleaded gasoline to 0.001 gram per gallon. The Occupational Safety and Health Administration (OSHA) also regulates the amount of lead in air. OSHA regulations limit the concentration of lead in workroom air to $50 \mu\text{g}/\text{m}^3$ for an eight-hour workday. Similarly, the Safe Drinking Water Act regulates the amount of lead allowable in potable water. The EPA limits lead in drinking water to 0.015 mg/L (EPA, 1995).

There is no universally accepted safe level for lead in the soil. The Centers for Disease Control set a level of 500 to 1000 mg/kg, as did the EPA in September 1989. These levels applied to residential sites, where direct exposure may occur (EPA, 1989). Direct exposure includes any activity where residents may come in contact with lead, such as children playing in lead contaminated soil. However, in January 1990, the EPA reiterated that these soil cleanup levels were guidance, and not binding regulation (EPA, 1990). A review of the current State of Maryland and federal references indicates that the level of lead above which soils may be considered contaminated has been lowered to 400 ppm. This determination is based on language in the following references:

- OSWER Directive #9355.4-12, dated July 14, 1994
- Office of Prevention, Pesticides, and Toxic Substances Guidance, dated July 14, 1994.

The OSWER Directive identifies "400 ppm as the residential screening level, the level above which there is sufficient concern that a site specific study of the risks should be conducted."

It must be noted that the aforementioned values are actually "action" levels. Sites which exceed the action level values do not require absolute remediation. The current trend is to move away from using single-value criteria for lead cleanup levels. Instead, federal agencies are proponents of using models that account for population, health, and environmental factors (EPA, 1995). The U.S. EPA is currently developing guidance recommending the use of the Uptake Biokinetic (UBK) model for determination of acceptable lead cleanup levels. This model integrates exposure from lead in air, water, soil, diet, dust, and paint with pharmacokinetic modeling to predict blood levels of lead in the most sensitive population of children up to six years in age. The model, however, does not apply to adults, and therefore is not appropriate for industrial settings. No recommended soil cleanup levels for lead at commercial or industrial sites exist at this time (EPA, 1995).

EPA has, however, published cleanup levels for areas other than residential. EPA's "Standards for Use and Disposal for Municipal Sewage Sludge" sets the maximum lead input to soil via sludge application at 300 kg/hectare, which converts to a soil lead concentration of approximately 150 mg/kg (Page and Chang, 1993). However, it should be noted that depth must be taken into consideration. Another approach for determining the acceptable levels of lead in soil is by examining the leachability of the lead in the soil. A procedure known as the Toxicity Characteristic Leaching Procedure,

or TCLP, is based on the amount of lead that may become solubilized in certain solvents and thus leach out into the environment. The acceptable TCLP level for lead is below 5 mg/L (Sternberg, 1997). However, TCLP testing is normally performed for the purpose of determining whether materials must be classified as hazardous waste.

Cleanup goals are by far the most important factor in consideration of remediation technology. Although cost versus benefit is a factor, a treatment option is useless if it is economical but does not meet the cleanliness standard set by regulation or developed from a site specific risk assessment. No absolute number exists above which remediation of lead contamination must be conducted. Facilities are recommended to perform site specific risk assessments to determine appropriate cleanup levels.

For the purposes of this study 400 ppm is considered the cleanup goal.

2.2.5 Risks of Lead:

Lead is considered to be one of the highest threats to the food chain because of its importance in environmental health, particularly relating to humans. Humans are exposed through air, water, and food intake; thus, the gastrointestinal tract and the respiratory system are major routes for lead absorption (Page and Chang, 1993). However, people may also be inadvertently exposed to lead from lead contamination in dust and soil. The concern for human health stems from potential child ingestion. Toddlers and infants ranging in age from 6 months to 6 years old are most at risk to lead contamination in the environment. Lead affects children in this age group more than the rest of society for two reasons:

- They engage in activities in which they are likely to ingest lead. These activities include chewing and sucking on materials containing lead, playing in lead contaminated soil, and high incidence of hand-to-mouth play.
- Lead becomes a neurotoxin for children in the 6 month to 6 year age group even when the lead exposure dose is relatively low and of short duration.

Neurotoxic effects include decreased intelligence, short-term memory loss, impairment of visual-motor functioning, hyperactivity, irritability, reading and spelling underachievement, and overall behavioral problems. Unfortunately, some of these neurotoxic effects are irreversible. Lead has also been classified as a probable carcinogen (Page and Chang, 1993).

There is no consensus on what level of lead in the blood is considered safe.

Varying levels of lead affect people in varying degree. A level that may produce severe effects on one child may not affect another. The Centers for Disease Control originally determined that child blood lead levels of about 25 $\mu\text{g}/\text{dl}$ indicate excessive absorption; they have since gradually decreased the number to the current level of 10 $\mu\text{g}/\text{dl}$ (Eidson and Tollestrup, 1995).

An interesting study was performed in New Mexico in 1991 comparing blood lead levels of nearby residents before and after remediation of an abandoned smelter site (Eidson and Tollestrup, 1995). Lead levels of up to 24,800 ppm existed in a smelter slag pile that was located twenty or more feet from residences. The cleanup lasted for less than a year. Prior to the cleanup, blood levels ranged from undetectable, or less than 5 $\mu\text{g}/\text{dl}$, to 29 $\mu\text{g}/\text{dl}$. After the cleanup, blood levels ranged from undetectable to only 10

µg/dl. In addition, the mean blood lead levels decreased by approximately 2 µg/dl for each of three towns studied. These decreases occurred within one year. Furthermore, the study showed that mean blood lead levels for people living near the smelter were significantly higher than those living further away, and the mean blood lead levels were much higher for households with a member working at a nearby lead battery plant than those who did not. Although decreases in blood lead levels were expected, the study shows the significant impact a contaminated area can have on residents living nearby. Generally, an increase in blood lead levels of 1-7.6 µg/dl for each 1000 ppm increase of lead in soil has been observed in studies conducted in urban areas and in areas operating smelters (Eidson and Tollestrup, 1993). However, it should be noted that these numbers vary depending on the forms of lead in the soil.

More detailed information on uses, transport, and contamination of lead can be found in Appendix B.

**SECTION 3:
REMEDIAL INVESTIGATION:
SITE CHARACTERIZATION**

3.1 Levels of Lead Contamination on Greenbury Point:

Greenbury Point is contaminated with varying levels of lead. Data exists from 1994 which indicates the varying degrees of contamination (Spectralytix, 1994). The data was originally used for land transfer purposes during the Base Realignment and Closure process, but it serves the present remediation needs well. In 1994, Naval Computer and Telecommunications Area Master Station (NCTAMS), the "parent" command of NRTF, contracted the sampling through Engineering Field Activity Chesapeake (EFA CHES), USNA's "parent" command. EFA CHES in turn contracted soil sampling through Spectralytix. Soil around both the towers and in residential areas were sampled.

3.1.1 Sampling Around Towers:

Samples were taken from the soil on March 1, 1994; received in the lab on March 3, 1994; and analyzed on March 10, 1994. Figure 3.1 is an illustration of sampling locations. The samples were taken from around the bases of the sixteen towers in two configurations:

- Tripod Towers: Five samples for each tripod tower were taken. Three samples were taken 5 feet from each leg towards the center of the tower, and 2 samples were taken at opposite sides of the perimeter of the base. The seven tripod towers include Towers E, F, G, L, M, N, and O.

- Guyed/One Support Towers: Five samples for each guyed tower were taken roughly equidistant from each other, approximately 5 to 7 feet from each leg, along the perimeter of the base. The nine guyed towers include Towers A, B, C, D, H, I, J, K, and P.

Sampling results are listed in Figure 3.2. Results indicate contamination ranging from no considerable contamination to high levels of contamination. For the purposes of this study, soils around the towers were classified as either non-contaminated, low, intermediate, or high level sites based on the amount of contamination indicated by the testing. This allowed for group analysis rather than analysis of each individual tower.

Non-contaminated sites were those that contained contamination below the 400 ppm level. Towers A, C, D, I, J, K, and P indicated low lead levels. Lead concentrations ranged from less than 10 mg/kg to 310 mg/kg.

Some contamination was discovered at Towers B, E, and H. These towers are considered low level sites because lead concentrations are generally below 1,000 mg/kg and only a few samples around each tower were above the 400 mg/kg level. Tower B had one sample at 680 mg/kg; Tower E had two samples at 410 and 1100 mg/kg; and Tower H had one sample at 600 mg/kg.

One Tower, Tower O, was in the intermediate range. Although all samples were high, they ranged from 650 to 2100 mg/kg.

Sampling at five of the towers resulted in their classification as high contamination sites. Soil around Towers F, G, L, M, and N indicate high levels of lead contamination. All samples but one for Towers F and G were high. Tower F had levels

ranging from 3000 to 8900 mg/kg, and Tower G had levels ranging from 4,000 to 9400 mg/kg. All samples for Towers L, M, and N indicated high levels of lead contamination. Soil around Tower L had levels ranging from 1,000 to 7,200 mg/kg; Tower M had levels ranging from 1,700 to 10,800 mg/kg; and Tower N had levels ranging from 530 to 8,600 mg/kg.

Five samples were taken at each tower. Table 3.1 lists average contamination values calculated for each tower:

Table 3.1: Contamination Values and Rankings for Towers.

Tower	Average (mg/kg)	Ranking (Highest to Lowest)	Classification
A	96	14	Non-contaminated
B	318	8	Low
C	40	16	Non-contaminated
D	149	12	Non-contaminated
E	474	7	Low
F	5466	3	High
G	6480	1	High
H	260	9	Low
I	162	11	Non-contaminated
J	228	10	Non-contaminated
K	123	13	Non-contaminated
L	3460	5	High
M	5920	2	High
N	4066	4	High
O	1366	6	Intermediate
P	68	15	Non-contaminated

An inspection of Figure 3.1 reveals that no apparent pattern for contamination exists. However, a rough geographic trend may be evident. It appears that the soil around the towers to the east of the point have little contamination. The soil around the towers in the middle area of the Point contain low levels, and the towers on the west end of the Point contain the highest levels of lead. It is reasonable to assume that all towers were at one time painted with lead based paint. They were all built before the dangers of

lead were known, and they were all repainted at least once during the time that most paint contained lead. Prevailing winds could be a possibility for the location of contamination. Another cause could be stripping operations for some of the towers conducted in years past.

Figure 3.1
Illustration of Sampling Locations
(Lorentzen, 1996)

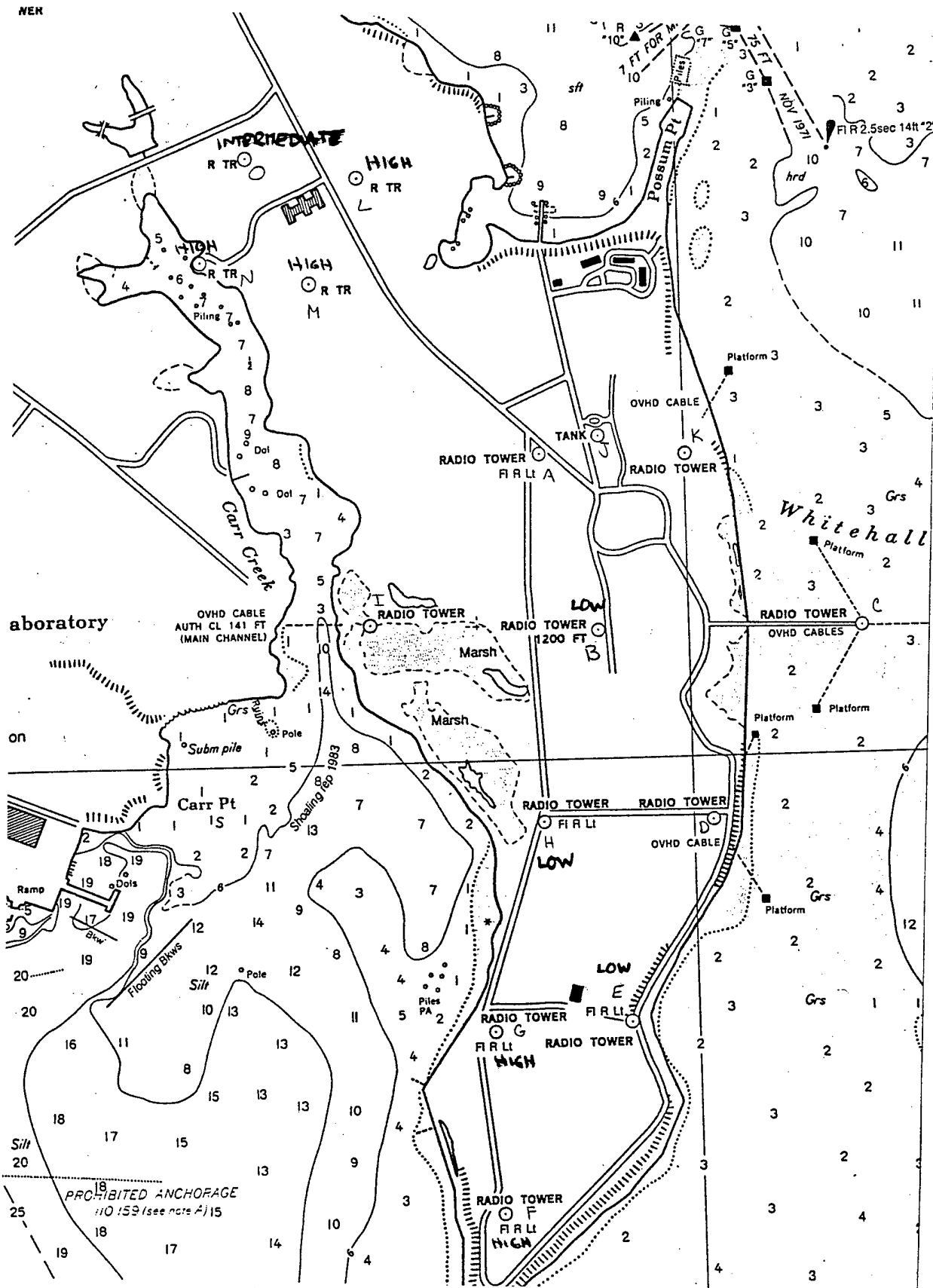


Figure 3.2

TOWER SAMPLING RESULTS

Tower A:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
A-1	70	10
A-2	210	10
A-3	80	10
A-4	100	10
A-5	20	10

Tower B:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
B-1	15	10
B-2	ND	10
B-3	260	10
B-4	ND	10
B-5	680	10

Tower C:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
C-1	ND	10
C-2	ND	10
C-3	ND	10
C-4	40	10
C-5	ND	10

Tower D:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
D-1	270	10
D-2	70	10
D-3	115	10
D-4	130	10
D-5	160	10

Tower E:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
E-1	350	10
E-2	ND	10
E-3	15	10
E-4	430	10
E-5	1100	10

Tower F:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
F-1	7200	10
F-2	8900	10
F-3	7900	10
F-4	330	10
F-5	3000	10

Tower G:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
G-1	9400	10
G-2	5300	10
G-3	9000	10
G-4	4700	10
G-5	4000	10

Tower H:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
H-1	360	10
H-2	100	10
H-3	110	10
H-4	130	10
H-5	600	10

Tower I:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
I-1	ND	10
I-2	ND	10
I-3	ND	10
I-4	13	10
I-5	310	10

Tower J:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
J-1	180	10
J-2	200	10
J-3	230	10
J-4	250	10
J-5	280	10

Tower K:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
K-1	160	3300
K-2	140	4600
K-3	70	1000
K-4	105	7200
K-5	140	1200

Tower L:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
L-1	3300	10
L-2	4600	10
L-3	1000	10
L-4	7200	10
L-5	1200	10

Tower M:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
M-1	6500	10
M-2	4400	10
M-3	10800	10
M-4	1700	10
M-5	6200	10

Tower N:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
N-1	530	10
N-2	8600	10
N-3	2500	10
N-4	1800	10
N-5	7200	10

Tower O:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
O-1	1800	10
O-2	980	10
O-3	1300	10
O-4	2100	10
O-5	650	10

Tower P:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
P-1	110	10
P-2	80	10
P-3	15	10
P-4	ND	10
P-5	ND	10

Background:

SAMPLE NUMBER	TEST RESULTS (mg/kg)	DETECTION LIMITS (mg/kg)
BG-1	ND	10

3.1.2 Sampling in Residential Areas:

Because high lead levels were found in the area of the towers, residential areas were also sampled. Soil samples were taken around housing units, playgrounds, and a school. Samples were taken from the soil on August 12, 1994; received in the lab on August 15, 1994; and analyzed on August 23, 1994.

Sampling results for residential areas are listed in Figure 3.3. Building and housing locations can be seen in Figure 3.4. Samples indicated that little contamination exists in the residential areas. No contamination above the 400 mg/kg level was found around the Primary School or in the playgrounds. The soil around Building 51 showed one high level, 418 mg/kg. Building B, which is a housing unit, did, however, indicate unusually high levels of lead. A sample from the North side of the house indicated a level of 7,220 mg/kg, and a sample from the Northwest corner indicated a level of 544 mg/kg. Because the family in this unit included a small child. The family was notified, advised of recommended precautions, and entered into the Navy's child blood lead level monitoring program.

Figure 3.3

RESIDENTIAL AREA SAMPLING RESULTS

Building 72:

Sample Number	Location	Test Results (mg/kg)	Detection Limits (mg/kg)
DT-1	East side, 12' behind building	113	10
DT-2	Northeast Corner, 5' from building	22	10
DT-3	North side, 12' from building	33	10
DT-4	Northwest corner, 10' from building	118	10
DT-5	West side (front), 15' from building	96	10
DT-6	Southwest corner, 8' from building	16	10
DT-7	South side, 15' from building	88	10
DT-8	Southeast corner, 7' from building	11	10

Building 71:

Sample Number	Location	Test Results (mg/kg)	Detection Limits (mg/kg)
DT-9	East side, 8' from building	232	10
DT-10	Northeast corner, 10' from building	41	10
DT-11	North side, 50' behind building	35	10
DT-12	Northwest corner, 10' from building	130	10
DT-13	West side, 12' from building	70	10
DT-14	Southwest corner, 15' from building	57	10
DT-15	South side, 15' from building	119	10
DT-16	Southeast corner, 10' from building	126	10

Building 51:

Sample Number	Location	Test Results (mg/kg)	Detection Limits (mg/kg)
DT-17	East side, 12' behind building	418	10
DT-18	NE Corner, 10' from building	66	10
DT-19	North side, 8' behind building	63	10
DT-20	NW corner, 50' from building	336	10
DT-21	West side, 12' from building	44	10
DT-22	SW corner, 12' from building	110	10
DT-23	South side, 12' from building	44	10
DT-24	SE corner, 8' from building	190	10

Playground:

Sample Number	Location	Test Results (mg/kg)	Detection Limits (mg/kg)
DT-25	Off circle driveway at NW end, 15' inside	25	10
DT-26	Off circle driveway at west side, 20' inside	21	10
DT-27	Off circle driveway at south side, 10' inside	21	10
DT-28	Southeast corner, 15' inside	32	10
DT-29	East side, 10' inside	53	10
DT-30	Northeast, 20' inside	52	10

Primary School:

Sample Number	Location	Test Results (mg/kg)	Detection Limits (mg/kg)
DT-31	Front, 12' off sidewalk	81	10
DT-32	Front, 40' from building	54	10
DT-33	Front Northeast corner, 15' from building	31	10
DT-34	North side, 50' from building	26	10
DT-35	North side, 10' from building	71	10
DT-36	Back corner (Northeast), 10' from building	129	10
DT-37	Rear, 30' from building	45	10
DT-38	Near sidewalk, 8' behind building	46	10
DT-39	Rear, 40' behind middle of school	19	10
DT-40	Near fence to golf course, 18' behind building	33	10

Building 298:

Sample Number	Location	Test Results (mg/kg)	Detection Limits (mg/kg)
DT-41	East side, 12' from building	28	10
DT-42	Northeast corner, 15' from building	37	10
DT-43	North side, 10' from building	30	10
DT-44	Northwest corner, 8' from building	29	10
DT-45	West side, 12' from building	39	10
DT-46	Southwest corner, 10' from building	24	10
DT-47	South side, 15' from building	29	10
DT-48	Southeast corner, 12' from building	31	10

Building A:

Sample Number	Location	Test Results (mg/kg)	Detection Limits (mg/kg)
DT-49	East side, 12' from building	27	10
DT-50	Northeast corner, 15' from building	46	10
DT-51	North side, 10' from building	152	10
DT-52	Northwest corner, 8' from building	115	10
DT-53	West side, 12' from building	164	10
DT-54	Southwest corner, 10' from building	92	10
DT-55	South side, 15' from building	120	10
DT-56	Southeast corner, 12' from building	121	10

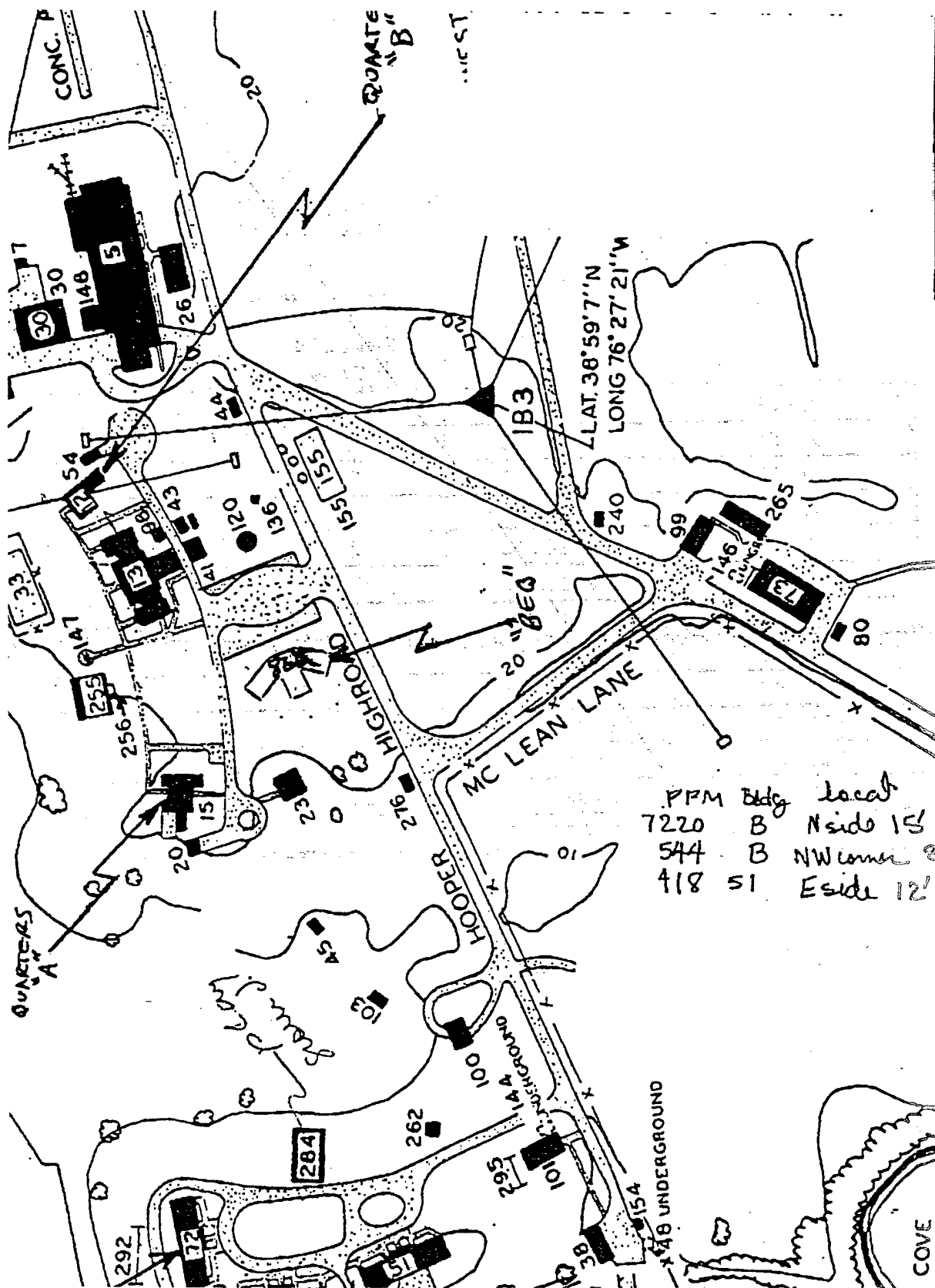
Building B:

Sample Number	Location	Test Results (mg/kg)	Detection Limits (mg/kg)
DT-57	East side, 10' from building	74	10
DT-58	Northeast corner, 12' from building	89	10
DT-59	North side, 15' from building	7220	10
DT-60	Northwest corner, 8' from building	544	10
DT-61	West side, 12' from building	39	10
DT-62	Southwest corner, 12' from building	55	10
DT-63	South side, 15' from building	199	10
DT-64	Southeast corner, 10' from building	63	10

Field Blanks:

Sample Number	Location	Test Results (mg/kg)	Detection Limits (mg/kg)
DT-65	20' inside gate to NRTF, off road	75	10
DT-66	Beside golf course driving range, off road	112	10
DT-67	Beside golf course, 200 yards from Primary School	49	10

Figure 3.4
Residential Sampling Locations
(Lorentzen, 1996)



3.2 Types of Soil on Greenbury Point:

The majority of Greenbury Point is covered by sandy and silty loams. Table 3.2 lists the types of soil found on Greenbury Point. The soils are listed in approximate descending order of quantity of area covered. Figure 3.5 is a depiction of where the soils are located (Lorentzen, 1996; USDA, 1973).

Large portions of both the western and eastern areas are covered by tidal marsh. The northwestern area is dominated by Keyport silt loam with minimal slopes. Moderately eroded Collington silt loam as well as Collington fine sandy loam with slopes ranging from 5 to 40 percent also cover the northwestern area. The northeastern area contains Monmouth fine sandy loam with various slopes as well as Monmouth clay loam. The mid-eastern area also contains Monmouth fine sandy loam in addition to Collington silt loam. The southern tip contains mainly Keyport silt loam, but Collington silt and fine sandy loam are also present on the southeastern coastline. Coastal beaches and cut and fill land exist along the majority of the remaining coastlines.

The types of soils which are contaminated vary. The following table delineates the contaminated soil types by tower:

Table 3.2: Soil Types Around Contaminated Towers.

Tower	Average (mg/kg)	Soil Type	Classification
B	318	Fine sandy loam, 0-2% slopes	Low
E	474	Silt loam, 0-2% slopes	Low
H	260	Fine sandy loam, 0-2% slopes	Low
O	1366	Silt loam, 0-2% slopes	Intermediate
F	5466	Monmouth urban land complex, 0-5% slopes	High
G	6480	Tidal marsh	High
L	3460	Silt loam, 0-2% slopes	High
M	5920	Silt loam, 0-2% slopes	High
N	4066	Silt loam, 0-2% slopes	High

The contaminated soils were determined by examining the type of soils underneath antenna towers which possessed high lead levels. It must be noted, however, that other contaminated soil types probably exist. The list presented only represents those areas that were tested. There exists a high probability that contamination extends further away from the towers into adjacent types of soils. Section 5 addresses additional data needs to determine extent of contamination.

Table 33
Types of Soil on Greenbury Point
(Lorentzen, 1996)

SYMBOL	DESCRIPTION	LOCATION
KpA	Keyport silt loam 0 to 2 percent slopes	Northwestern area Mid-Eastern area Southern tip
Tm	Tidal marsh	Mid-Western and Mid-Eastern area Southwestern coastline Northern area
MvA	Monmouth fine sandy loam 0 to 2 percent slopes	Northeastern area Mid-Eastern area
MwC3	Monmouth clay loam 5 to 10 percent slopes Severely eroded	Northeastern area Central area Southern area
CoB2	Collington fine sandy loam 2 to 5 percent slopes Moderately eroded	Southeastern area
MxB	Monmouth-Urban land complex 0 to 5 percent slopes	Northeastern area Southern area
MvB2	Monmouth fine sandy loam 2 to 5 percent slopes Moderately eroded	Northeastern area Central area
CpB2	Collington silt loam 2 to 5 percent slopes Moderately eroded	Northwestern area Central-Eastern area
CuD	Cut and fill land 5 to 15 percent slopes	Central Western coastline
CuB	Cut and fill land 0 to 5 percent slopes	Northeastern coastline
CoE	Collington fine sandy loam 15 to 40 percent slopes	Northwestern coastline Southeastern coastline
CoC3	Collington fine sandy loam 5 to 10 percent slopes Severely eroded	Northwestern area Central-Eastern area
DnA	Donlonton fine sandy loam 0 to 2 percent slopes	Central area
CoD3	Collington fine sandy loam 10 to 15 percent slopes, severely eroded	Central Eastern area to coast
MuB2	Monmouth loamy sand 2 to 5 percent slopes Moderately eroded	Northern area
MvE	Monmouth fine sandy loam 15 to 40 percent slopes	Northeastern area to coast
MwD3	Monmouth clay loam 10 to 15 percent slopes Severely eroded	Eastern area

Table 3.3 (CONTINUED)

Mt	Mixed alluvial land	Central area
KpB2	Keyport silt loam 2 to 5 percent slopes Moderately eroded	Central-Eastern area to coast
CpA	Collington silt loam 0 to 2 percent slopes	Southeastern coastline
MxD	Monmouth urban land complex, 5-15% slopes	Northwestern area
CpuD	Collington urban land complex, 5-15% slopes, Comus silt loam	Northwestern area
MuC2	Monmouth fine sandy loam, 5-10% slopes, eroded	Northeastern area
Ce	Coastal beaches	Northeastern point

Figure 3.5
Soil Type Locations
(Lorentzen, 1996)



3.3 Other Site Conditions:

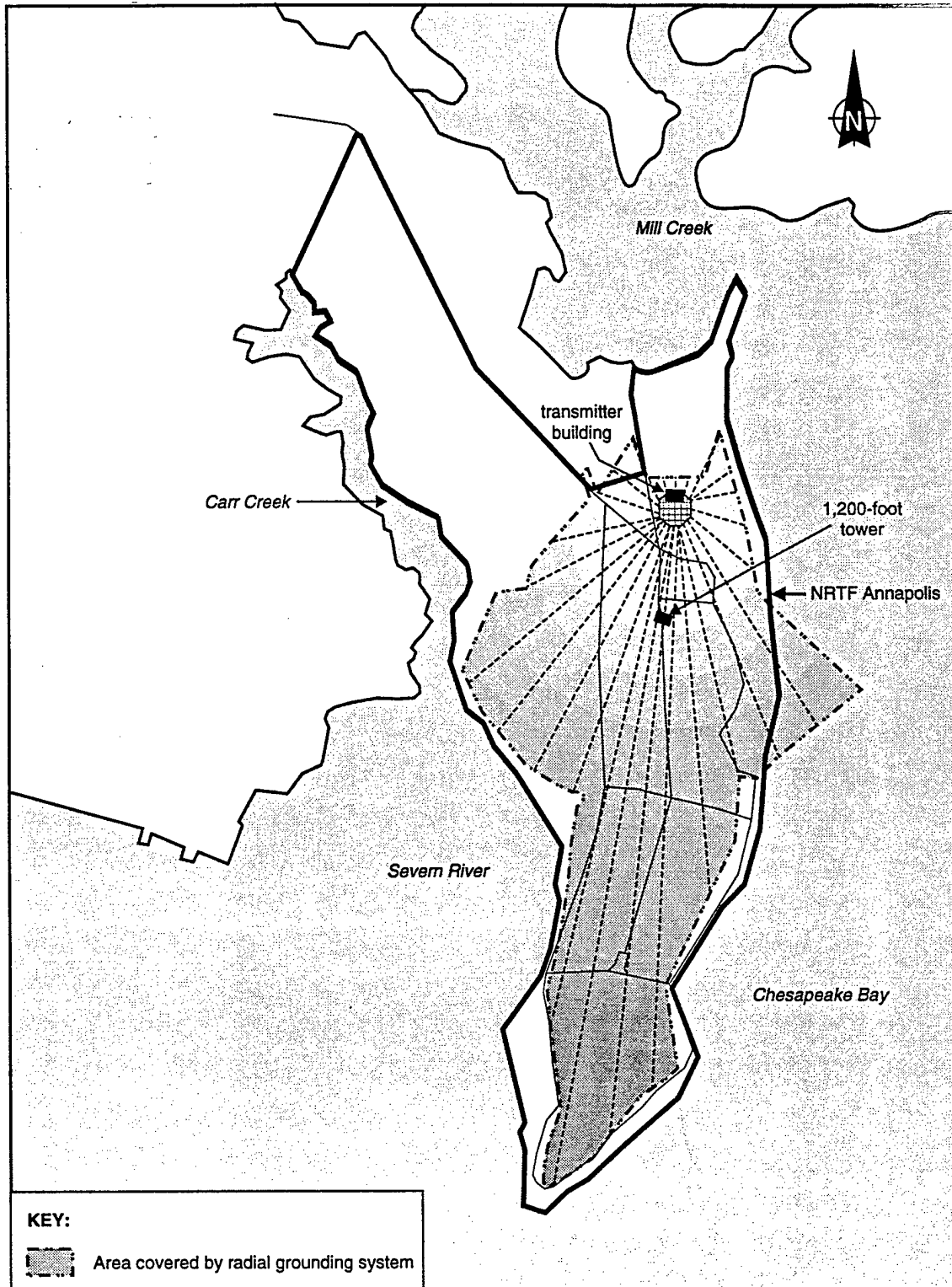
3.3.1 Underground Utilities:

Most of the underground utility lines are located in the residential areas. Relatively few underground utilities exist on the uninhabited portions of the Point. The few buildings on the south and mideastern ends of the point have no water or sewer service. There are, however underground electric cables which should be avoided during any remediation operations (USNA, 1996).

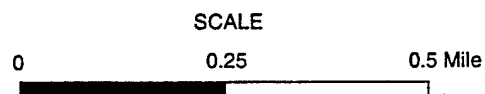
3.3.2 Copper Grounding System:

A copper grounding system exists on the majority of Greenbury Point. It is buried 6 to 10 inches beneath the surface of the soil, and consists of approximately 3 inch diameter exposed copper wire. The system extends 360 degrees radially outward from Building 5, its point of origin (Brunner, 1997). Figure 3.6 is a depiction of the copper grounding system. Because the Navy may plan to use the towers in the future, the copper grounding system should not be disturbed during remediation operations.

Figure 3.6
Copper Grounding System



SOURCE: Ecology and Environment, Inc. 1996



RADIAL GROUNDING SYSTEM AREA, NRTF ANNAPOLIS

SECTION 4:
FEASIBILITY STUDY:
DEVELOPMENT AND SCREENING OF ALTERNATIVES

4.1 General:

This section provides an overview and screening of the treatment technologies available today. Various proven remediation technologies exist, and many more are currently under development. Treatment of metals in soils is a particularly well developed field, but much room for improvement exists. The challenge in developing a remediation plan for a particular site is not in inventing a way to clean up the contamination, but in determining what available option best suits the needs of the site. Many factors come in to play, including the level of cleanliness desired and cost versus benefits of various options. Evaluation of treatment approaches requires consideration of the nature, advantages, disadvantages, and degree of establishment of the technology.

4.2 Remediation Approaches:

Remediation options approach cleanup of contamination in one of two ways:

- treatment by immobilization of the contamination
- treatment by separation and concentration of the contamination (EPA, 1995).

Immobilization refers to the reduction of the mobility of contaminants in soil and groundwater. This approach reduces infiltration of fluids into the contaminated media by using barriers or by modifying the permeability of the contaminated matrix.

Immobilization can also reduce the solubility of the contaminant; this ultimately reduces the mobility of the contaminant in the groundwater. Separation and concentration, on the other hand, refers to the physical removal of the contaminant from the matrix. It can be

accomplished using physical or chemical means. Some technologies also allow for the recovery of usable metals.

A survey of Records of Decision (RODs) performed in 1993 indicated that over 70 percent of lead contaminated sites were treated with some type of immobilization technology, usually stabilization or disposal in a landfill permitted to receive hazardous waste (Paff and Bosilovich, 1995). Less than 10 percent of sites were treated with separation technologies, and less than 10 percent used reclamation processes to recover usable lead. The remaining sites were treated by incineration because the material to be treated contained large amounts of organics and heavy metals. The incineration process destroys organics, and lead contaminated ash remains which is still hazardous and requires some type of treatment or disposal by one of the two remedial approaches (Paff and Bosilovich, 1995).

Furthermore, treatment can take place while the soil is still in the ground (in-situ) or after it has been excavated (ex-situ). The remediation technologies available today can be categorized into three main groups: In-Situ Technologies; Ex-Situ Technologies; and Technologies which may be utilized as either In-Situ or Ex-Situ processes.

4.3 Description and Screening of Alternatives:

4.3.1 No Action Alternative:

Consideration of the "No Action Alternative" is required for every screening of remediation processes. This alternative is unacceptable due to the threat to human health and the environment posed by the existing lead contamination (Destafney, 1997). This

alternative is inconsistent with the Navy's future plans for utilization of Greenbury Point and should not be considered further.

4.3.2 In-Situ Technologies:

In-Situ technologies are advantageous because they do not require excavation of the soil. The soil can be treated in place, and clean replacement fill is unnecessary. This is a preferred alternative when contamination spreads over a vast area, rendering excavation cost prohibitive. Three types of In-Situ technologies exist: containment, soil flushing, and electrokinetic treatment.

4.3.2.1 Containment:

Containment is a type of immobilization technology. It is a rudimentary technology in which capping, vertical barriers, and horizontal barriers are used to keep the contamination limited to a restricted area. This type of technology is useful for waste management facilities or hazardous waste landfills, but is not applicable to residential sites or areas traversed by people (EPA, 1995)

Containment, though a very effective technology, is not applicable for use at Greenbury Point. The Naval Academy plans to maintain the land in its natural state and continue to use it. Capping, vertical barriers, or horizontal barriers would not be consistent with its planned use.

4.3.2.2 Soil Flushing:

Soil flushing is a type of separation and concentration treatment technology (EPA, 1995). It works by extracting contaminated materials from the ground's subsurface without excavation of the soil. Instead, aqueous solutions are injected into or

sprayed onto the area of contamination. The contaminated mixture is then collected and pumped to the surface for removal, recirculation, or on-site treatment and reinjection (EPA, 1995).

Soil flushing works by mobilizing the contaminated material (EPA, 1995). This occurs through one of three mechanisms:

- solubilization
- formation of emulsions
- chemical reaction with the flushing solutions.

The fluid used can be water, a solution of chemicals in water, or an organic solution.

The fluid passes through the contamination zone and picks up the contaminant. The fluid is then collected by strategically placed wells or trenches, and subsurface containment barriers are often used to help control the flow of the fluid to the wells. Finally, the fluid is brought to the surface for disposal, recirculation, or on-site treatment and reinjection.

One key to efficient soil flushing operation is the ability to reuse the flushing solution. A variety of water treatment techniques can then be used to recover the metals and allow the fluid to be reused (EPA, 1995).

Advantages:

Many flushing solutions are available that are accessible at sufficient quantity and reasonable cost. Some of the more common flushing solutions include (EPA, 1995):

- | | |
|---------------------|----------------------------------|
| • water | • carbonic acids |
| • sulfuric acid | • sodium hydroxide |
| • hydrochloric acid | • chelating or complexing agents |
| • nitric acid | • reducing agents |
| • phosphoric acid | • surfactants |

This process is especially effective against water-soluble or water-mobile constituents, as water will extract them. It is also effective with inorganics that can be flushed from the soil with water, including the carbonates of nickel, zinc, and copper. Adjustment of pH can also be used in this technology to render it more effective. For example, acid solutions can be used to remove cationic metals or basic organic materials, and basic solutions can be used to remove some metals and some phenols (EPA, 1995).

Disadvantages:

Soil flushing technology may be difficult to apply if the soil is not easily wet with the flushing solution. Installation of subsurface drains, barriers, and collection wells may also be complicated and difficult to accomplish if underground utilities exist in the area. Furthermore, the risk is encountered of not achieving the desired level of treatment. This factor depends on the contact of the flushing solution with contaminants, the appropriateness of the solution for the contaminants, and the hydraulic conductivity of the soil. Another disadvantage is that this process is lengthy due to the contact time necessary between the flushing solution and the contaminants. Therefore, addition of soil flushing chemicals may be necessary to speed the contaminant removal. Lastly, this technology possesses the potential for introducing harmful chemicals into the groundwater system. This may create a pollution problem in itself; injection of treatment chemicals may trigger the requirement for land disposal. Therefore, the chemical treatment agents selected must be compatible with the environment, and Land Disposal Restrictions (LDRs) on introducing chemicals into the soil must be consulted in the selection of reagents (EPA, 1995).

Degree of Establishment and Effectiveness:

Soil flushing has been established to varying degrees. While soil flushing to remove organic materials has been established on both bench- and pilot-scale, inorganic treatment is less well developed. Several systems for organics are in operation, and many systems are being designed for remediation of Superfund sites. Most of the applications involve the remediation of VOCs. Inorganic treatment, on the other hand is less developed. Operational treatment has been reported at one site contaminated with metals as well as organics and at another site contaminated with chromium. The EPA reports that there are three other sites which plan on using the technology to remediate inorganics, including chromium, lead, nickel, and mercury (EPA, 1995).

Compatibility with Existing Site Conditions:

Soil flushing at first appears to be a viable option for treatment of lead contamination at Greenbury Point. Because contamination spreads over a vast area, extraction of the contaminant from the subsurface without excavation of the soil seems reasonable. However, there are several barriers to the effectiveness of this treatment strategy. First, compounds of lead are for the most part insoluble over the normal pH range of soil. This severely restricts the number of flushing solutions available for use with lead. A review of 123 compounds of lead in the CRC Handbook reveals that most inorganic lead compounds are either insoluble, very slightly soluble, or only slightly soluble. Table 4.2.1 lists the compounds which possess solubilities greater than 1 g/100cc.

Table 4.3.1: Compounds with Solubilities Greater than 1g/100cc:

(CRC Handbook, 1985)

Compound	Solubility (Cold Water)	Solubility (Hot Water)
PbBr ₂	.4554	4.71
Pb(ClO ₃) ₂	very soluble	very soluble
Pb(ClO ₃) ₂ •H ₂ O	151.3	171
Pb(ClO ₄) ₂ •3H ₂ O	499.7	-
PbSiF ₆ •2H ₂ O	soluble	very soluble
Pb(CHO ₂) ₂	1.6	20
Pb(NO ₃) ₂	37.65	127
Pb(OH)NO ₃	19.4	soluble
3PbO•N ₂ O ₃ •H ₂ O	very soluble	-
PbS ₂ O ₆ •4H ₂ O	115	-

From this table, however, it can be seen that chloride and nitrate salts of lead do exhibit high solubility. Thus, hydrochloric acid and nitric acid are possible components of flushing solutions which may be effectively used with lead. Furthermore, at pHs of 10 and above, Pb tends to resolubilize as Pb(OH)₃⁻ (EPA, 1995). Thus, by altering the pH, soil flushing may be a viable option.

Underground utilities would probably pose minimal problems. Although some utilities do exist, subsurface drains and barriers could probably be installed in ways which avoid them. The copper grid system, on the other hand, could pose a problem if the Navy plans to keep the towers for possible reuse in the future. If the grounding system needs to be left intact, soil flushing would be impossible. The grounding system covers such a vast area that installation of subsurface drains and barriers could not be accomplished without destroying the integrity of the system.

Furthermore, the soils on Greenbury Point do not exhibit high moisture content (Lorentzen, 1997). The majority of the Point is covered by fine, silty, and sandy loams (USDA, 1973). The areas of known contamination, in particular, are composed of sands

and silts. The only known contaminated area which is saturated is the tidal marsh around Tower G. Because tidal marshes on Greenbury Point are considered wetlands, it may not be feasible to inject chemicals into that area (Davis, 1997; Verdone, 1997). Injection of foreign substances, particularly acids, is also not environmentally desirable. They may contaminate the groundwater and would trigger the requirement for land disposal. This technology is also not fully established for inorganics. Thus, selection of soil flushing as a remediation strategy would only be sound if other more developed strategies were either impossible or too costly to implement.

Comparison with Ideal Parameters:

Table 4.3.2 compares existing site conditions with ideal parameters for use of soil flushing.

Table 4.3.2: Comparison of Site Conditions with Ideal Parameters for Soil Flushing.

Parameter**	Limits**	Greenbury Point
Hydraulic Conductivity	$>10^{-3}$ cm/sec; low clay content	Low clay content *
Contaminant Solubility in Water	$>1,000$ mg/L	Unknown
Complexity of Waste Mixture	Less is beneficial	Not complex *
Spacial Variation in Waste Composition	Less is beneficial	Unknown
Flushing Fluid Characteristics	Low toxicity, low cost, and allow for treatment and reuse;	Depends on fluid selected
	Should not plug or have other adverse effects in the soil;	Depends on fluid selected
	Low viscosity	Depend on fluid selected
Cyanides, Sulfides, and Fluorides	Low is preferred	Low *
Specific Surface Area of Matrix	<0.1 m ² /g	Unknown
Cation Exchange Capacity (CEC)	$<$ about 50 to 100 meq/kg	Awaiting data
Humic Acid Content	Low is preferred	Unknown

* indicates a known favorable factor.

** information on ideal parameter limits obtained from EPA, 1995

More detailed information on reasoning for ideal parameters is supplied in Appendix C.

4.3.2.3 Electrokinetic Treatment:

Electrokinetic treatment is another type of separation and concentration treatment technology (EPA, 1995). Metals and other contaminants are removed from the soil and groundwater by application of an electric field in the soil's subsurface (Acar and Alshawabkeh, 1996). The charged electric field induces movement of ions, particulates, and water through the soil. The soil acts as a charged porous medium; it typically has a negative surface charge. The application of the electric field is accomplished through placement of anodes and cathodes in the soil. Most metals form positively charged ions that migrate toward the negatively charged electrode. The metals that form negatively charged ions migrate toward the positively charged electrode. Thus, concentration gradients are formed between the cathode and the anode. The electrical field continuously drives the metal ions from areas of low concentration to areas of high concentration. Water also flows toward the cathodes as a result of viscous drag from the movement of the cations (EPA, 1995).

The cathode and the anode are housed in wells which are spaced apart depending on site specific factors. They are also equipped with collection casings and circulation systems. The casings are filled with different chemical solutions, and the choice of chemical depends on the metal being collected and should allow for maximal recovery. The circulation system then brings the solution to the surface for subsequent treatment in a purification system. A variety of water treatment methods are available to allow for the removal of the recovered metal and make the fluid suitable for reuse (EPA, 1995).

Advantages:

Electrokinetic treatment is effective in dealing with chemical species that form ions in solution; the ions migrate under the influence of the electrical field and can be effectively concentrated (EPA, 1995). The technology can also be used for dewatering, as mobility of fluids is enhanced by the electroosmosis associated with the technology.

Another advantage is that electrokinetic treatment is less dependent on high soil permeability than other in-situ technologies, namely soil flushing. In electrokinetics, the separation occurs due to ionic migration rather than solely fluid flow. It is most applicable to saturated soils with nearly static groundwater flow and moderate to low permeability. The technology can even be used in fine-grained clay soils; in fact, it is established that these types of soils are the ideal medium for electrokinetic treatment (EPA, 1995). Thus, the technology can be applied where soil flushing flow rates are too low for soil flushing to be practical.

Disadvantages:

Electrochemical reactions are the major disadvantage of electrokinetic technology (EPA, 1995). The reactions occur both at the electrodes as well as in other areas of the soil. At the electrodes, electrolysis of water can occur. Hydrogen gas and hydroxide ions are formed at the cathode. When the hydrogen gas escapes, the pH can rise as high as 13. Likewise, oxygen and hydrogen ions are formed at the anode, causing acidification. During the electrokinetic treatment process, the acid front moves away from the anode and may cause dissolution of the metal contaminants. Other reactions which occur elsewhere in the soil include the oxidation of chloride ions to form chlorine gas. Solid

materials may also be precipitated from electrochemical reactions. For example, iron and chromium hydroxides may be formed, plug pores in the formation, and reduce the permeability of the soil to unsuitable levels (EPA, 1995).

Degree of Establishment and Effectiveness:

Electrokinetic Treatment is still under establishment. Pilot testing and field testing are ongoing under the SITE Demonstration Program (EPA, 1995). Bench-scale tests of soil treatment are being conducted to remove many contaminants. These include arsenic, benzene, cadmium, chromium, copper, ethylbenzene, lead, nickel, phenol, trichloroethylene, toluene, xylene, uranium, and zinc. 90% contaminant removal has been reported from clay-like soils, but only 65% removal has been observed in porous soils. A 450% concentration factor for metal contaminants has also been observed in water adjacent to the electrodes (EPA, 1995). However, the electrokinetic treatment technology is still in the early development stage and has not yet proven to be fully effective against lead contamination.

Compatibility with Existing Site Conditions:

Electrokinetic treatment is one of the lesser preferred alternatives for remediating lead contamination on Greenbury Point. For one, lead is one of the more immobile metals in soil (Mench et al., 1994). Thus, it will be difficult to implement this treatment technology. Whereas chemicals may be used in soil flushing to render the metal more soluble and this more mobile, this cannot be done in electrokinetic treatment. Water is used as the flushing solution in electrokinetics, and the chemicals are used in the

collection casings. Thus, the chemical does not come into contact with the metal until after it has migrated.

Electrokinetic treatment is also not advantageous because the soil on Greenbury Point is fairly permeable. The treatment should be considered for application when soil flushing flow rates are too low for soil flushing to be practical, and this is not the case on Greenbury Point. Electrokinetic treatment is most applicable to saturated soils with nearly static groundwater flow and moderate to low permeability; clay soils are an ideal medium. However, Greenbury Point contains almost no clay soils at all.

Electrokinetic treatment is too risky to attempt at this time. In addition to environmentally harmful electrochemical reactions which may occur, only 65% removal of contamination has been observed from porous soils (EPA, 1995). Although several pilot and field tests for treatment of lead using electrokinetics are ongoing, the technology is not established enough for use.

Comparison with Ideal Parameters:

Table 4.2.3 compares existing site conditions with ideal parameters for use of electrokinetic treatment.

Table 4.3.3: Comparison of Site Conditions with Ideal Parameters for Electrokinetic Treatment.

Parameter**	Limits**	Greenbury Point
Hydraulic Conductivity	Preferably low	Probably high
Depth to Water Table	Saturated	Unknown
Areal Extent of Contamination	Well defined	Unknown
Electroosmotic Permeability	Well understood	Unknown
Cation Exchange Capacity (CEC)	Low	Awaiting data
Metals Analysis	Well defined	Only lead *
Salinity	Low	Unknown

* Indicates a known favorable factor.

** information on ideal parameter limits obtained from EPA, 1995

More detailed information on reasoning for ideal parameters is supplied in Appendix C.

4.3.4 Ex-Situ Technologies:

Ex-situ technologies are advantageous because they do not leave contamination remaining in the soil; therefore, threat to human health and the environment is eliminated. Ex-situ technologies are also more amenable to recovery of metals in elemental form or as marketable compounds. Recovery for reuse not only allows for effective cleanup, but helps with pollution prevention goals as well. However, recovery is a sensible alternative only if a market exists for the material. Three types of Ex-situ technologies exist: physical separation/concentration, soil washing, and pyrometallurgical separation.

4.3.4.1 Physical Separation/Concentration:

Physical separation/concentration is, as its name suggests, a type of separation and concentration treatment technology (EPA, 1995). This process has long been used by the mining industry to extract desired metals from a mineral ore and has more recently been applied to remediating metals from contaminated soil. It can involve gravity separation, froth flotation, size separation, and hydroclones, to name a few. Separation of the particles from one another can be accomplished by:

- Particle size
- Particle density
- Surface properties of the particles
- Magnetic properties of the particles (EPA, 1995).

Table 4.3.4 lists the more common particle separation techniques. All of these techniques involve a series of steps that lead to successive products containing increasing

concentrations of the desired metal. Each step results in the feed being divided into two streams, called concentrate and tailings. Because physical separation techniques are not 100% efficient, each stream contains some amount of the other. A third stream, termed middlings, is sometimes created to increase separation efficiency. This stream contains a metal concentration between the concentrate and tailings. Each of these streams is then separated again until the desired level of metal concentration is achieved (EPA, 1995).

A process called comminution is sometimes used in mining as a preceding method to the aforementioned physical separation techniques (EPA, 1995). The mineral is crushed and ground to produce a particle size amenable to the physical separation techniques. Comminution is useful in soil remediation to break up soil lumps to a more appropriate size. However, screening is the most common practice in soil remediation to isolate the particle sizes which are more responsive to treatment (EPA, 1995).

Table 4.3.4: Particle Separation Techniques.

(EPA, 1995)

	Basic Principle	Major Advantage	Major Disadvantage	General Equipment	Lab Test Equipment
Screen Sizing	Various diameter openings allow passage of different effective particle sizes	Inexpensive	Screens can plug, fine screens are fragile, dry screening produces dust	Screens, sieves, wet or dry trommel	Vacuum sieve or screen, trommel
Classification by Settling Velocity	Faster vs. slower settling due to particle density, size, shape of particles	Continuous processing, long history, reliable, inexpensive	Difficulty with clay-like, silty, and humic soils	Mechanical, non-mechanical, hydrodynamic classifiers	Elutriation columns
Gravity Separation	Differences in density, size, shape, and weight of particles	Economical, simple to implement, long history	Ineffective for fine particles	Jigs, shaking tables, troughs, sluices	Jig, shaking table
Magnetic Separation	Magnetic susceptibility	Simple to implement	High capital and operating costs	Magnetic separators	Lab magnets
Flotation	Suspend fines by air agitation, add promoter-collector agents, fines collect in floating froth	Very effective for some particle sizes	Contaminant must be small fraction of total volume	Flotation machines	Agitair™ laboratory unit

Advantages:

The major advantage of physical separation techniques is their cost. This process can be used alone or as a pretreatment to reduce the volume of material to treat by another method. Pretreatment is advantageous when another more costly method will be used to meet final cleanliness standards. Physical separation can reduce the expense by ridding the soil of contamination that can be isolated, and leaving the contamination that cannot be isolated to the more costly method. Major advantages for each of the more common separation processes are listed in Table 4.3.4.

Disadvantages:

The major disadvantage of physical separation techniques is that they are only suitable to soils containing particles of certain qualities. This process is limited to soils in which the metal contamination meets one of the following two conditions:

- The contamination is in the form of discrete particles in the soil.
- The contamination is limited to a specific particle size range and the contamination is adsorbed onto soil particles.

In the first case, any of the physical separation/concentration techniques can be used. In the second case, physical separation based on particle size is normally used. The size ranges amenable to several techniques are presented in Table 4.3.5.

Table 4.3.5: Particle Size Ranges Applicable To Separation Processes. (EPA, 1995)

Separation Process	Particle Size Range
Screening	
Dry Screen	> 3,000µm
Wet Screen	> 150 µm
Hydrodynamic Classifiers	> 50 µm
Elutriator	5-150 µm
Hydroclone	5-100 µm
Mechanical Classifier	
Gravity Concentrators	
Jig	> 150 µm
Spiral Concentrator	75-3,000 µm
Shaking Table	75-3,000 µm
Bartles-Mozley	5-100 µm
Table	
Froth Flotation	5-500 µm

Although application of the technology to particles of limited size range can be considered a disadvantage, it should be noted that the technologies are more applicable to treatment of the more common sized particles. It works best on particles in the intermediate size range (between 100 and 1,000 µm). Because soil usually contains a wide range of particle sizes, however, sufficient results normally cannot be achieved using a single technique. Thus another disadvantage of physical separation processes is that a combination of processes must normally be used to achieve sufficient separation. Major disadvantages for each of the more common physical separation techniques are listed in Table 4.3.4.

Degree of Establishment and Effectiveness:

Physical separation/ concentration technologies have a long history and are well established for the removal of metals from mineral ores. However, the technology has not been proven effective for metal contamination until fairly recently. Furthermore, sites at which the technology has been tested have had varying degrees of success. While

at some sites physical separation was the only technology necessary to reach cleanliness standards, others were forced to follow physical separation treatment by other methods. At the very least, however, physical separation is effective in reducing the levels of metals in the soil. The performance depends upon the size range and density difference of the feed material.

The effectiveness of physical separation/concentration technologies in removing metal contamination from soils can be predicted (EPA, 1995). The soil must simply be characterized and analyzed to determine whether it meets the ideal parameters. Two elements are needed:

- the particle size range distribution
- the amount of contamination in each particle size range.

This can be accomplished by passing the soil through sieves of various sizes and conducting a metals analysis on each resulting size range.

An even more precise method exists for determining whether the gravity separation technique will be effective. If the density difference between the soil and contaminant particles is significant, gravity concentration techniques should perform well (EPA, 1995). Although the true test will be actually conducting the separation, efficiency of separation can be estimated by a "concentration criterion" formula:

$$cc = \frac{S_h - S_f}{S_l - S_f} \quad (4.1)$$

where S_h = specific gravity of heavy particles (usually metal contamination)
 S_f = specific gravity of separation fluid medium (usually water)
 S_l = specific gravity of light particles (usually soil).

If cc is greater than 2.5, gravity separation can be expected to perform well. Separation should still be feasible if cc is between 1.25 and 2.5, and is probably not effective below 1.25. Sample concentration criteria for lead are illustrated in Table 4.3.6.

Table 4.3.6: Sample Concentration Criteria Values for Lead in Gravity Separation. (EPA, 1995)

Heavy Material Type	Heavy Metal Specific Gravity	CCs for Various Specific Gravities		
		Light Material Specific Gravity		
		2.2	2.4	2.6
Lead Metal, Pb	11.3	8.6	7.4	6.4
Lead Oxide, PbO	9.3	6.9	5.9	5.2

Effectiveness of physical separation techniques can also be improved through the adjustment of equipment related variables (EPA, 1995). For example, water can be added or removed from materials to maintain optimal solids level control in gravity separators. Gravity separation is also more effective when particles are first separated according to size range by sieve analysis. Small particles should also be removed, as they reduce processing rate and separation efficiency.

The physical separation/concentration technology has been found to be particularly effective against certain types of lead contamination. One study of note is the research conducted in 1993 by a Bureau of Mines Research Center (BMRC) for the Naval Civil Engineering Laboratory (NCEL), now known as the Naval Facilities Engineering Service Center (NFESC). The Navy is faced with the problem of remediation of lead contamination at small arms ranges. Lead on the ranges is present in the form of particulates from the bullets and bullet fragments as well as molecular adsorbate. NCEL and BMRC tested the use of physical separation to remove the particulate lead; they planned on subsequently using stabilization or soil washing to treat the adsorbed lead (Nelson, 1997; Royer, 1997). In pilot studies, the physical separation

techniques recovered a significant amount of lead from soils taken from various sites. In fact, one site passed the TCLP test without having to undergo any further treatment. Several problems were encountered, however. Most problems related to lead being trapped on various portions of the apparatus used to separate the lead. The final separation scheme is depicted in Figure 4.1. All the equipment on the flowchart is expected to fit on two or three 40 foot by 8 foot trailers, with a throughput of 1.5 tons per hour. This type of system is currently in operation and is commercially available through various vendors (EPA, 1995).

Compatibility with Existing Site Conditions:

Physical separation/concentration appears to be very applicable to soils on Greenbury Point. In addition to being one of the more cost effective treatment technologies, the conditions on the Point match desirable parameters for the technology. Because the contamination is due to flaking and chipping of lead based paint from the antenna towers, the lead is in the form of discrete particles in the soil. Though any of the physical separation/concentration techniques can be used if this condition exists, choice of a technique may be limited due to particle size. It appears that this technique will be especially applicable because most of the soils on the Point are fine and silty. Thus, heavier lead contaminated particles should be easily separated. This technique has also been recently established for remediating lead contamination, and the Navy as a whole is using this technique in remediating lead contaminated small arms ranges. In addition, many vendors offer services using this option (BDM, 1997).

Before deciding to use this technique, however, further analysis must be completed. A determination of the size of particles containing contamination should be made and differences in soil and contaminated particle size should be verified. The specific gravity of the soil should also be determined. Section 5 addresses additional data needs required for further analysis. Equation 4.1 and parameters listed in Tables 4.3.4 and 4.3.5 can then be a reference for determining whether screening, classification by settling velocity, gravity separation, or flotation should be used.

Comparison with Ideal Parameters:

Table 4.3.7 compares existing site conditions with ideal parameters for use of physical separation/concentration.

Table 4.3.7: Comparison of Site Conditions with Ideal Parameters for Physical Separation/Concentration.

Parameter**	Limits**	Greenbury Point
Particle Size	See Table 4.1.5	Unknown
Contaminant Metal Concentration (in each size class)	Higher concentration in specific size classes favorable.	Unknown
Concentration Criteria	cc > 2.5 favorable cc > 1.25 acceptable	Unknown
Moisture Content	Low moisture favorable for dry separations; high moisture favorable for wet separations.	Low *
Particle shape	Variable	Variable *
Waste complexity	Fewer types of metals preferred	Lead only *
Spacial Variation	Homogeneous preferred	Unknown
Magnetic Properties	Ferromagnetism	No
Floatability	Hydrophobic surface	Hydrophobic (insoluble) *

* indicates a known favorable factor.

** information on ideal parameter limits obtained from EPA, 1995

More detailed information on reasoning for ideal parameters is supplied in Appendix C.

(EPA, 1995)



4.3.4.2 Soil Washing:

Soil washing is another type of separation/containment technology and is similar to the in-situ treatment method of soil flushing (EPA, 1995). Soil washing is actually a combination of two other remediation methods, but so commonly used that it can be described as a process in itself. Soil washing combines physical separation techniques and extraction techniques (EPA, 1991).

The physical separation step is necessary in soil washing to first separate the particles on which the contamination rests. Contaminants tend to bind chemically and physically to clay and silt particles. The clay and silt also tend to attach physically to sand and gravel. The particle size separation step of soil washing separates the silts and clays from the clean sand and gravel particles. In addition, the subsequent extraction step requires intimate contact between the contaminated soil and the extraction fluid. The physical separation helps remove large clumps and debris that interfere with good contact. Not only does the physical separation step aid in the effectiveness of the follow-on extraction, but it reduces the volume of material requiring treatment as well (EPA, 1995).

The extraction step is necessary for final removal of the pollutants. While the separation described in the previous section was for the purpose of separating particles based on size, density, and similar characteristics, the separation in soil washing involves extracting metals using chemical means. Extraction technologies include chemical leaching and physical scrubbing. These processes depend primarily upon metal solubility in water and chemical leaching agents to extract the metals. Soluble contaminants are

scrubbed from the particle surfaces and dissolved into a liquid phase. Processing typically involves several volumes of washing water or leach solution per unit volume of soil treated. Soil washing solutions can range from pure water to concentrated acids or bases (EPA, 1995).

Once the two soil washing processes are completed, the soil is tested for contamination removal and returned to the site or reclaimed. The extraction fluid and silt and clay mix contain high concentrations of contaminants; it must subsequently be treated or disposed of. Chemical leaching solutions are often regenerated for reuse to recover economic value as well as to avoid environmental impacts associated with disposal. The extraction fluid can be further processed to recover the metals in some cases. The most common methods of "purifying" the extraction solution are ion exchange and solvent extraction (EPA, 1995).

Advantages:

Soil washing is not capital intensive and therefore a more economical option than pyrometallurgy. It is most advantageous when the metal concentration is low, in the range of several percent to parts per million. It is also most effective when small quantities need to be treated. However, soil washing may also be more cost effective than other methods for treating larger volumes (EPA, 1995).

Another advantage is that additives can also be used to increase the separation capabilities of the extraction fluid. They include surfactants, acids, and chelating agents. Acids aid in removal of metals which are tightly bound to the soil and for which less aggressive techniques are ineffective. Acid leaching uses the solubility of metals in acid

solutions to transfer metals from the waste to solution. Chelating agents similarly react with metals to form water-soluble metal-chelate complexes. Three of the more common chelating agents used are citric acid, ethylenediaminetetraacetic acid (EDTA), and diethylenetriaminepentaacetic acid (DTPA). Chelating agents can, however, be expensive and difficult to recover (EPA, 1995).

Disadvantages:

Selection of extraction fluid can be challenging. Although an extraction fluid can be found to remove almost any metal contaminant, each fluid is normally limited to a small range of specific chemical forms of metals. Thus, most extraction fluids are only effective for a narrow range of contaminant and matrix combinations. Four elements must be taken into consideration when selecting an extraction fluid:

- Compatibility of the solution with the contaminated media
- Cost of the solution
- Possible side reactions with the mixture of contaminants present
- Ability to treat or regenerate the solution.

Due to the confining nature of the extraction solution, soil washing is limited to soils where only one metal contaminant exists (EPA, 1995).

Degree of Establishment and Effectiveness:

Soil washing is fairly well developed and commercially available from a large number of vendors. The technology has more often been used to remove organics, but it is becoming increasingly used to remediate metals in contaminated soils. Soil washing is currently being used for full-scale remediation of approximately 7,000 tons of lead

contaminated soil at a site in Minnesota. It is the selected remedy at over 20 Superfund sites, several of them battery recycling sites contaminated with lead (EPA, 1995).

Compatibility with Existing Site Conditions:

Because the amount of soil requiring treatment is so large, soil washing may also be a viable option. Although this technology is most effective when only small quantities require treatment, it also helps reduce the cost of treating larger volumes. If upon remediation using physical separation/concentration, it is found that the soil is not cleaned to the acceptable level of 400 ppm, soil washing could be used. It helps reduce the amount of material which must be treated with more costly methods. Because the first step in soil washing is actually physical separation, this technology would only require further treatment by chemical extraction. It is this step on which analysis is focused.

The extraction step depends on solubility, and thus many of the same obstacles encountered in analysis of soil flushing are now encountered here. The choice of extraction chemicals is limited; it must be a chemical which renders lead soluble. Lead soluble compounds are listed in Table 4.3.1. As can be seen from the table, hydrochloric acid and nitric acid are again possible chemicals which may be effective. Raising pH may also enhance solubility, as lead tends to resolubilize as $\text{Pb}(\text{OH})_3^-$ at pHs greater than 10. However, it also promotes adsorption and complexation.

On the other hand, extraction is applicable on Greenbury Point because it is suitable for soils with only one contaminant present. Due to limited operations on Greenbury Point, lead is most likely the only contaminant in the soil. Thus, an extraction

fluid specifically for leaching lead can be used without negative side effects of other contaminants. Because the treatment is ex-situ, the negative factor of injecting foreign substances in the soil is nonexistent. However, ex-situ treatments require large areas to be excavated due to the large extent of contamination on Greenbury Point.

Soil washing is fairly well established, currently in use to remediate lead contaminated sites, and commercially available. Overall, soil washing's apparent compatibility with lead removal at Greenbury Point demands further investigation.

Comparison with Ideal Parameters:

Table 4.3.8 compares existing site conditions with ideal parameters for use of soil washing.

Table 4.3.8: Comparison of Site Conditions with Ideal Parameters for Soil Washing.

Parameter**	Limits**	Greenbury Point
Particle-Size Distribution	> 2 mm 0.25-2 mm 0.063-0.25 mm <0.063 mm	Falls within one of these ranges *
Clay Content	Low is preferred	Low *
Type and Size of Debris	None is preferred	None *
Complexity of Waste Mixture	Less is beneficial	Lead only contaminant *
Waste Composition Variation	Homogeneous material preferred	Homogeneous *
Waste Buffering Capacity and pH	Low is preferred with acid extraction	Depends; pH 4.5 to 7.4
Cyanides, Sulfides, and Fluorides	Low is preferred	Low *
Cation Exchange Capacity (CEC)	≈ 50-100 meq/kg	Awaiting data
Humic Acid Content	Low is preferred	Unknown
Extraction Fluid Characteristics	Low toxicity, low cost, and allow for economic treatment and reuse	Depends on selection of fluid
Equilibrium Partitioning of Contaminant Between Matrix and Extraction Fluid	> 1,000 mg/L metal in extractant desired	Depends on selection of fluid
Contaminant Solubility in Water	> 1,000 mg/L	< 1,000 mg/L

* indicates a known favorable factor.

** information on ideal parameter limits obtained from EPA, 1995

More detailed information on reasoning for ideal parameters is supplied in Appendix C.

4.3.4.3 Pyrometallurgical Separation:

Pyrometallurgical Separation is another type of separation and concentration treatment technology. It is a process whereby high temperatures are used to treat metal contaminated solids for recovery of the metals. The metals are in the form of metal, metal oxide, ceramic product, or other useful forms. Like physical separation/concentration, pyrometallurgical separation has a long history. In fact, it is the oldest type of metal processing; its earliest recorded use was in 3,000 B.C. At that time, the technique of converting copper oxide ores to copper metal by heating with charcoal was already well established (EPA, 1995).

Pyrometallurgical Processes for waste treatment typically consist of primary and secondary treatments. The primary treatment involves converting compounds in the waste matrix to metal and transferring undesirable components to a separate slag phase. The secondary treatment is for the purpose of upgrading the metal. The process usually requires a reducing agent, fluxing agents, and a heat source. The fluxing agents facilitate melting and slag off impurities. Volatile metals enter the off-gas stream while the nonvolatile metals remain in the furnace. The metals in the gas stream are then oxidized and recovered by filtration or scrubbing while the metals in the furnace are purified by slagging (EPA, 1995).

Advantages:

Pyrometallurgical separation's advantages lie mainly in the fact that great amounts of material can be treated. The process is most applicable to large volumes of material containing metal concentrations higher than 5 to 20 percent (EPA, 1995). It is particularly effective with cadmium, chromium, lead, nickel, and zinc. Pyrometallurgical separation is also advantageous because the high temperatures used in the process increase the rate of reaction. They also lower the reactor volume necessary because they make the reaction equilibrium more favorable (EPA, 1995).

Disadvantages:

Pyrometallurgical processing can rarely be used alone. A uniform feed material must first be attained. The uniform material is required for effective heat transfer between the gas and solid phases. Particulates in the off-gas must also be restricted. The range of particle sizes which achieve these criteria are limited. The presence of large clumps is detrimental because they slow heat transfer, so they must be removed. Fine particles are also undesirable because they get caught in the gas flow, increasing the volume of dust which must be removed from the flue gas. Uniform feed material can be accomplished by physical separation processes or by pelletization. Physical separation can also help to reduce the volume of feed material. A reducing agent and flux are also sometimes mixed in prior to pelletization to ensure proper contact between the treatment agents and the contaminated material (EPA, 1995).

Degree of Establishment and Effectiveness:

Pyrometallurgical Separation is a very well established technology. This is due to laws which regulate the large volume of electric arc furnace (EAF) emission control waste. Next to EAF dust, its greatest capacity lies in the recovery of lead from various solid wastes. Other metals for which the technology is particularly applicable are mercury, copper, nickel, and tin (EPA, 1995).

Although the process does have a long history, different pyrometallurgical technologies continue to be tested today. Flame reactor technology was tested under the Superfund Innovative Technology Evaluation (SITE) Demonstration Program in 1991 (EPA, 1995). Secondary lead smelting is also now being tested on materials which contain 1 and 50 percent lead, and many commercial secondary lead smelters exist. Blast furnaces heat the waste, and the lead is subsequently removed by a combination of melting and reduction. Waste materials being tested include battery cases, slags, lead dross, and lead paint chips. So far, it has been used to treat approximately 2.7 million pounds of lead-bearing materials from Superfund sites (EPA, 1995). More detailed information on reasoning for ideal parameters is supplied in Appendix C.

Compatibility with Existing Site Conditions:

Pyrometallurgical separation is extremely effective in treating lead contaminated soils. However, various conditions must exist in order to guarantee its effectiveness. Although the situation at Greenbury Point conforms to the requirement for large volumes to be treated, it does not meet most of the other conditions. Metal concentrations in the soil are not greater than 5 to 20 percent; thus, use of this treatment technology would not

be prudent. The possibility exists of using physical separation first to increase the percentage of lead in the soil. However, the technology has only been efficiently demonstrated at concentrations greater than 40 percent, and physical separation would not guarantee that the pretreated material would meet this goal. Furthermore, the primary purpose of pyrometallurgical separation is for the recovery of metals; this is clearly not the goal at Greenbury Point. The lead is not in easily recoverable form. Paint chips, as opposed to lead bullets, are very difficult to reclaim.

Thus, pyrometallurgical separation should not be considered further.

4.3.5 Technologies With In-Situ and Ex-Situ Applications:

Several technologies can be applied to both excavated soils and to soils which remain in place during treatment. Not only does each technology have several advantages, but each soil option has its own advantages as well. Thus, a process can be chosen based on both technology and site needs. Two remediation methods exist which possess both in-situ and ex-situ applications: solidification/stabilization and vitrification.

4.3.5.1 Solidification/Stabilization:

Solidification/Stabilization (S/S) is also a type of immobilization technology. Solidification/Stabilization operates on the premise of physically locking the contaminant in a solidified matrix, which can be a soil-like mixture or a monolithic block. It serves one of two purposes:

- to alter the physical or leaching characteristics of the waste
- to decrease the toxicity of the waste (EPA, 1995).

S/S achieves its purposes by accomplishing the following:

- Improving the physical characteristics of the waste by producing a solid from a liquid or semi-liquid waste. This does not necessarily reduce the aqueous mobility of the contaminant.
- Reducing the solubility of the contaminant.
- Decreasing the exposed surface area where mobility of contaminants may occur.
- Limiting the contact of transport fluids of contaminants.

Chemical processes are normally used to convert the contaminant to a more immobile form. Typically, treatment agents are injected into the contaminated soil to microencapsulate the waste particles. Inorganic or organic binders may be used. In addition to microencapsulation, some solidification/stabilization methods may reduce chemical leach resistance. Still other methods operate on the basis of encasing macroscopic particles in an impermeable coating, yet they leave the waste itself unaltered. Solidification/Stabilization of contamination while the soil remains in the ground requires both mixing and off-gas treatment. Two of the most common types of solidification/stabilization technologies involve using cement based binders or polymer microencapsulation (EPA, 1995). Both of these methods are discussed in detail.

4.3.5.1.1 Cement Based Solidification/Stabilization Technologies:

Cement-based S/S technologies include Portland-type cements, pozzolanic materials, sodium silicate, and cement/silicate systems (EPA, 1995). The hydration reactions of all these inorganic cement based binders work to tie up free water. Thus, the mobility of contaminated particles is limited through several mechanisms:

- formation of insoluble hydroxides, carbonates, or silicates

- substitution of the metal into a mineral structure
- sorption
- physical encapsulation

One factor that must be kept in mind when determining a suitable system for immobilization is that increase in binder addition increases the volume of treated waste. Other additives may be necessary to help immobilization depending on the type of contamination (EPA, 1995).

Advantages:

Cement Based S/S technologies can be used if a single metal is the predominant contaminant in the soil (EPA, 1995). The technology is particularly effective when the contaminating metal is cadmium or lead, as they both form insoluble hydroxides in the pH ranges typically found in cement. It must be noted, however, that they may resolubilize if pH is not carefully controlled. This technology can also be used even when low levels of organics are present

Disadvantages:

Numerous limiting factors exist in the use of cement-based S/S technologies. One disadvantage of in-situ cement-based solidification/stabilization technologies is that due to these chemical treatments, they possess the potential for introducing oxidizing, reducing, or neutralizing chemicals into the groundwater system. This may create a pollution problem in itself; injection of treatment chemicals may trigger the requirement for land disposal. Furthermore, metals that do not have low solubility hydroxides and species that exist as anions are difficult to stabilize reliably. This technology can also not

be used if the soil is contaminated with more than one metal because it is difficult to determine treatment and disposal conditions for which all contaminating metals are immobilized. A fourth disadvantage is that this technology is not suited toward use in soils where high organics exist. The mixing process and heat generated by cement hydration reaction can increase organic vapor losses due to the presence of VOCs in the soil (EPA, 1995).

Degree of Establishment and Effectiveness:

Cement-based S/S technology is well established and commercially available. Studies by the EPA indicate that cement-based S/S is effective against lead contamination. As a matter of fact, S/S is considered the Best Demonstrated Available Technology (BDAT) for lead contaminated wastes (EPA, 1995). The EPA examined 280 sites where lead contamination ranged from 110 to 670,000 mg/kg. After treatment, reduction in leachable lead was as high as 99.9 percent (EPA, 1995).

However, lead is subject to leaching and solubilization in the presence of even mildly acidic leaching solutions. At pHs of 10 and above, Pb tends to resolubilize as $\text{Pb}(\text{OH})_3$. Furthermore, it has been noted that lead can cause a pronounced retardation of the early hydration of calcium silicate cements. This is a problem when choosing Portland type cement or pozzolan as the binder; the predominant mechanism for immobilization using these binders is the precipitation of hydroxides. The possibility of treating lead contamination by the formation of anglesite (PbSO_4) and apatite ($\text{CaCClF}(\text{PO}_4)_3$) is now under investigation in the SITE Program (EPA, 1995).

Compatibility with Existing Site Conditions:

Many factors favor the use of cement based S/S for treating the soil at Greenbury Point. Not only is lead the single contaminant found in the soil, but this treatment has been shown to be particularly effective against lead. Because high organic contamination also does not exist, the danger of releasing VOCs from heat generation of the cement hydration reaction is erased. Furthermore, no chemical constituents exist in the soil which may interfere with the solidification/stabilization process.

Use of this technology at Greenbury Point, however, comes into question when considering its performance in-situ or ex-situ. Ex-situ treatment would require excavation and treatment of the soil as waste. In turn, clean fill would have to be returned to the site. Because contamination covers such a large area, this process would probably not be cost effective. When considering in-situ treatment, characteristics of the bound material must be considered. The contamination at Greenbury Point is confined to the upper layers of the soil. No data is available on the depth of contamination, but it can be reasonably estimated to within ten inches from the surface (Davis, 1997; Lorentzen, 1997; Verdone, 1997). This process may work well for contamination well below the soil's surface, where effects of the binder are not visible. However, cement-bound soil would not be compatible with USNA's plans for exhibiting the Point as a conservation area. Furthermore, in-situ treatment runs the risk of introducing undesirable chemicals into the groundwater system.

Despite these undesirable factors, this technology should not be eliminated from consideration. Where ideal parameters are known for cement-based S/S, they are all

favorable. Because of the process' compatibility with ideal parameters as well as its classification as the BDAT for lead contaminated wastes, the process warrants further investigation.

Comparison with Ideal Parameters:

Table 4.3.9 compares existing site conditions with ideal parameters for use of cement-based solidification/stabilization.

Table 4.3.9: Comparison of Site Conditions with Ideal Parameters for Cement-Based Solidification/Stabilization.

Parameter	Limits	Greenbury Point
Organic Content	<20-45% by wt	Unknown
VOC Content	<50 ppb	<50 ppb *
SVOC Content	organics < 10,000 ppm	<10,000 ppm *
Oil and Grease Content	<10% by wt	<10% by wt *
Phenol Content	<5%	<5% *
Particle Size	Limited amt of insoluble particulate passing through a 200 mesh screen	Unknown
Cyanide Content	<3,000 mg/kg	<3,000 mg/kg *
Sulfate Content	<1500 ppm for Type I Portland cement or use cement formulated to tolerate higher sulfate levels	Unknown

* indicates a known favorable factor.

** information on ideal parameter limits obtained from EPA, 1995

More detailed information on reasoning for ideal parameters is supplied in Appendix C.

4.3.5.1.2 Polymer Microencapsulation Solidification/Stabilization:

S/S based on polymer microencapsulation works by immobilizing the contamination using thermoplastic or thermosetting resins. Bitumen, otherwise known as asphalt, is the least expensive and most prevalent thermoplastic resin utilized. In this treatment process, the waste and the resin are heated and mixed at elevated temperatures of approximately 130 to 230 degrees C (EPA, 1995). An extrusion machine is typically used to mix and heat the materials. During this process, any water or volatile organics

present in the waste boil off and are collected for treatment or disposal. The remaining treated material, which is a stiff, plastic resin, is also collected for possible reuse as paving material (EPA, 1995). Thermosetting resins have been used in limited applications.

Advantages:

Polymer microencapsulation can be used to treat low-level radioactive wastes, and organic binders have been tested or applied to wastes containing metals, inorganic salts, PCBs, dioxins, and arsenic (EPA, 1995). Because polymer microencapsulation works primarily by physical encapsulation in a water-insoluble organic resin, this application is particularly well-suited to treating water soluble salts such as chlorides or sulfates that are generally difficult to immobilize in cement-based S/S systems.

Disadvantages:

Numerous disadvantages exist with the use of polymer microencapsulation S/S technologies. For one, polymer microencapsulation requires more complex equipment, more complicated operations, and more energy than cement-based S/S. Polymer microencapsulation also requires that the waste be within many limits so that it may be compatible with the organic binder. Furthermore, the waste cannot contain oxidizers such as nitrates, chlorates, and perchlorates (EPA, 1995). Oxidants present the potential for oxidation, which leads to concerns of safety as well as degradation of the waste.

Degree of Establishment and Effectiveness:

Polymer Microencapsulation S/S technology is fairly well established and commercially available. However, it is mainly used in limited applications where the

soil conditions meet optimal parameters and the treated waste is planned for reuse as paving material. The reuse helps offset the cost of the complex equipment, operations, and energy use of this technology. Polymer microencapsulation's effectiveness against lead contamination has been tested and proven effective (EPA, 1995).

Compatibility with Existing Site Conditions:

Some favorable factors exist for consideration of polymer microencapsulation in treating soils on Greenbury Point. For one, the technology is undoubtedly effective in treating lead contamination when thermoplastic rather than thermosetting resins are used. The danger of volatile organic compounds is also negligible.

However, the soil probably does not meet other required parameters. The water content of the soil may not be suitable. Technology descriptions state that high water content may cause the treated product to be too fluid, but they fail to detail the level that is considered high. Though most of the soils are not clays, the sands and silts may still hold an unacceptable level of water. A high probability of the existence of oxidizing agents, particularly nitrates, also exists. Soil testing in various areas of Greenbury Point indicates that nitrates are present (Cooperative Extension Service Soils Data, 1997). These will cause degradation of the treated material. Furthermore, immobilization of lead in cement based systems is also not a problem. Therefore, the more complex equipment, complicated operations, and increased energy required would provide no value. Concerns similar to those for cement based technologies also exist when considering whether to treat the material in-situ or ex-situ. In-situ treatment would alter

the conditions of the visible layers of soil and may introduce foreign substances into the groundwater. Ex-situ treatment would require large volumes of clean fill.

Although polymer microencapsulation has been tested and proven effective against lead contamination, its use should be considered further only if USNA plans on showcasing remediation of Greenbury Point as a pollution prevention project. Although cost should not be a primary factor in the selection of a treatment strategy, the higher costs of microencapsulation are a consideration. Although the reuse would not offset the increased costs over cement based technologies, the use of the treated product as paving material could provide a prime public relations opportunity for USNA. If so, water content and oxidizing agent requirements should be investigated further. Otherwise, polymer microencapsulation should not be considered for subsequent evaluation.

Comparison with Ideal Parameters:

Table 4.3.10 compares existing site conditions with ideal parameters for use of polymer microencapsulation S/S.

Table 4.3.10: Comparison of Site Conditions with Ideal Parameters for Polymer Microencapsulation Solidification/Stabilization.

Parameter**	Limits**	Greenbury Point
Water Content	Dry solid feed	Unknown
Oxidizing agents, such as nitrates, chlorates, and perchlorates	Low presence	Moderate presence
Organic Solvents	Low presence (particularly aromatic solvents)	Low *
Oils, Greases, and Chelating Agents	Low presence	Low *
Thermally Unstable Materials	As thermally stable as the binder	Low *

* indicates a known favorable factor.

** information on ideal parameter limits obtained from EPA, 1995

More detailed information on reasoning for ideal parameters is supplied in Appendix C.

4.3.5.2 Vitrification:

Vitrification is another type of containment technology. The vitrification process refers to the production of usable products from wastes. It pertains to the application of high-temperature treatment to contaminated soils for the purpose of reducing the mobility of metals. In addition to incorporating the metals in a vitreous mass and immobilizing them in a stable oxide solid, vitrification also destroys or vaporizes organic contaminants. Although this technology possesses both in-situ and ex-situ applications, its operation in these two mediums is very different.

4.3.5.2.1 Ex-Situ Vitrification:

Vitrification is used to treat excavated wastes contaminated with only metals, or with metals and organics (EPA, 1995). The contaminated soil is treated and converted to a useful product, such as clean fill, aggregate, erosion control blocks, paving blocks, or road dividers. The type of product produced depends on what type of material is added during the vitrification process, whether it be sand, clay, or native soil.

Vitrification is successful when the metals are retained in the melt during heating and subsequently incorporated into the vitrified mass that forms as it cools (EPA, 1995). The formation of crystalline phases in the melt must be prevented, as they decrease the resistance of the vitrified product. The crystalline phases can be minimized by solubilizing the metals retained in the melt. The approximate solubility of some elements in silicate glasses are shown in Table 4.3.11.

Table 4.3, 11 : Approximate Solubility of Elements in Silicate Glasses.**(EPA, 1995)**

Solubility	Elements
Less than 0.1 wt%	Ag, Ar, Au, Br, H, He, Hg, I, Kr, N, Ne, Pd, Pt, Rh, Rn, Ru, Xe
Between 1 and 3 wt%	As, C, Cd, Cr, S, Sb, Se, Sn, Tc, Te
Between 3 and 5 wt%	Bi, Co, Cu, Mn, Mo, Ni, Ti
Between 5 and 15 wt%	Ce, F, Gd, La, Nd, Pr, Th, B, Ge
Between 15 and 25 wt%	Al, B, Ba, Ca, Cs, Fe, Fr, K, Li, Mg, Na, Ra, Rb, Sr, U, Zn
Greater than 25 wt%	P, Pb, Si

It must be noted, however, that the actual solubility depends on the waste matrix and glass formulation.

Advantages:

Vitrification is an attractive form of waste treatment because it can process widely different materials. Because vitrification is applicable to wastes of many different forms, it can be used to convert wastes which are in the form of liquids, slurries, sludges, combustible or noncombustible solids, or combinations of these states. Both organics and inorganics can be treated. The process can also be adjusted to produce products with specific characteristics, such as chemical durability. Furthermore, the process additives of sand, clay, and native soil are low cost. The glass product from the vitrification also occupies less volume than the waste feed.

Disadvantages:

The major disadvantage of vitrification is cost. One of the significant expenses is the amount of energy required for the process. Energy requirements can range to over 2,500 kJ/kg (EPA, 1995). Actual energy requirements may vary, depending on process losses, water content, and energy sources present in the feed. Depending on local energy costs, different sources of energy can be used to minimize costs. For example, coal can

be added to contaminated soil; its oxidation near the molten glass interface offsets the electrical cost.

Vitrification also requires a multi-stage complete remediation process. This typically consists of waste excavation; pretreatment; mixing; feeding; melting; off-gas cleanup; recycling of filtered off-gas material; and casting the discharged melted material. Pretreatment operations include drying, desorption, segregation of metal components, and size reduction of the material (EPA, 1995). Chemical pretreatment may also be required to convert some metals to less volatile forms, as more volatile metals are difficult to retain during the vitrification process. An afterburner may also be required if the waste feed contains a high level of organics (EPA, 1995).

Degree of Establishment and Effectiveness:

Vitrification is not widely used because it is expensive to implement and it is not widely available from commercial vendors. However, there are a collection of vitrification systems under development. The technology is being tested in the treatment of nonhazardous, hazardous, and radioactive wastes. The purpose of these tests is mainly to reduce capital and energy costs for the melter. The most variation occurs in the design of the melter and the type of fuel used. Heat sources include fossil fuels such as coal, natural gas, and oil in the melter (EPA, 1995).

Vitrification technologies are applicable to lead contaminated soil. However, vitrification is most applicable to barium, beryllium, copper, nickel, silver, thallium, and zinc. Arsenic, lead, and selenium will be incorporated into the oxide melt, but with more

difficulty (EPA, 1995). More detailed information on ideal parameters can be found in Appendix C.

Compatibility with Existing Site Conditions:

Ex-situ vitrification can be used to treat lead contaminated soils, and several factors at Greenbury Point favor its use. For the most part, however, vitrification is not the most preferred method for treating lead contaminated soils because lead is not especially easy to incorporate into the oxide melt. Furthermore, Greenbury Point does not possess various parameters to which this technology is especially well suited. Vitrification is mainly used when problems exist with the waste which makes it impossible to utilize other methods. Thus, one of the more common treatment methods can be used. As with other ex-situ processes, a large amount of clean fill material will be required.

Although pollution prevention efforts could be highlighted through the formation of glass from excavated material, the benefits far outweigh the costs of the technology. Therefore, ex-situ vitrification should not be considered for further evaluation.

4.3.5.2.2 In-Situ Vitrification:

In-situ vitrification also converts contaminated soils to a glass and crystalline structure. However, an electrical current is passed through the contaminated soil to melt it and convert it to the monolith. Electrodes are placed in trenches filled with graphite and glass frit to allow the current to travel. Resistance heating in these trenches transfers heat to the soil, which then begins to melt. Consequently, the soil becomes conductive. The melt grows in size as the power is gradually increased to full operating level. The

soil melt must have the ability to carry current during heating and to solidify upon cooling (EPA, 1995). Therefore, two primary soil and sludge requirements exist (EPA, 1995):

- They must be composed of glass forming materials like silica.
- They must contain a minimum alkali content (combined Na_2O and K_2O) of 1.4 percent by weight.

Advantages:

In-situ vitrification can treat large contaminated areas. A single melt can treat a region of up to 1,000 tons and about 20 feet in depth (EPA 1995). Even larger areas can be treated by vitrifying in stages to form one large monolith. Another advantage of in-situ vitrification is the requirement for little or no pre- and post- treatment. In addition, the technology is applicable to a wide variety of sludges and soils, including (EPA, 1995):

- sandy, silty, and clay-like soils
- those containing both hazardous organic and inorganic contaminants
- those containing high concentrations of combustible debris, concrete, rock, and scrap metal. Tanks and drums, however, should not be present.

Disadvantages:

As with ex-situ vitrification, the major disadvantage of in-situ vitrification is its cost. The amount of energy required often makes this technology cost prohibitive. Another disadvantage is that volatile contaminants like mercury, arsenic, and organics

may be difficult to capture and treat. They may also migrate through the subsurface (EPA, 1995).

Degree of Establishment and Effectiveness:

Although in-situ vitrification has proven to be very effective, the technology is not widely used (EPA, 1995). This is primarily due to the costs associated with the process. In addition to long-term effectiveness, the technology reduces toxicity, mobility, and volume. More than 150 tests and demonstrations at various scales have been performed on a variety of waste types in many different soils (EPA, 1995). The technology has been used on a large scale at least ten sites (EPA, 1995). However, some improvements are needed for melt containment and air emission control systems. As with ex-situ vitrification, the technology is applicable to lead contaminated soils. More detailed information on ideal parameters for use of this technology is supplied in Appendix C.

Compatibility with Existing Site Conditions:

Many factors on Greenbury Point seem to favor the use of in-situ vitrification. The contamination covers a large area, and no tanks or drums exist in the area being considered for vitrification (Lorentzen, 1997). Furthermore, no special requirements are needed; VOCs are not present, so an off-gas hood is not called for, and the contaminated areas possess adequate depth. Although the contaminant depth is above the desired 6 feet, this is not a problem because lead is not a very volatile metal.

Once again, however, lead is not one of the contaminants most suited to vitrification due to its relative difficulty in incorporation into the oxide melt. Greenbury Point also does not have some of the negative factors which preclude other methods.

Furthermore, some of the contaminated areas on Greenbury Point which have not yet been defined may contain greater than 5 percent slopes. Although relatively few in number, underground utilities also exist closer than 20 feet from the melt zone.

Although in-situ vitrification is applicable, it should not be considered for further evaluation due to its high cost and the availability of other treatment methods.

SECTION 5: REMAINING TECHNOLOGIES AND DATA NEEDS

5.1 Technologies Remaining for Further Consideration:

The number of technologies requiring further analysis was reduced from ten to three.

The technologies and remaining data needs for each are listed in Table 5.1.

Table 5.1: Technologies Requiring Further Analysis:

Technology	Data Required
Physical Separation/Concentration	Specific gravity of soil Soil particle sizes Contaminant metal concentration in each size class Spatial variation of soil particles Depth of contamination
Soil Washing	Particle size distribution Soil buffering capacity Humic acid content Determination of extraction fluid -characteristics (toxicity, cost, allows for treatment and reuse) -equilibrium partitioning of lead between soil and extraction fluid Depth of contamination
Cement Based Solidification/Stabilization	Organic content of soil Particle size Sulfate content Depth of contamination

Polymer microencapsulation may also be considered if the Naval Academy plans to highlight the remediation of Greenbury Point as a pollution prevention initiative. If so, the water content of the soil is a data parameter that is needed for this technology.

The data needs in Table 5.1 are by no means all inclusive. These data requirements are listed for the sole purpose of determining whether the technology is applicable to the site. Other criteria need to be considered in the more detailed analysis of the remaining technologies.

5.2 CERCLA Evaluation Criteria:

In the more detailed analysis, the CERCLA process requires that nine evaluation criteria be considered in the selection of an alternative:

- Overall protection of human health and the environment;
- Compliance with ARARs (or meet criteria for waiver);
- Long-term effectiveness and permanence, including consideration of residual risk resulting from remaining, untreated waste and adequacy and reliability of controls;
- Reduction of toxicity, mobility, or volume through treatment or recycling, including the type of waste remaining after the cleanup;
- Short-term effectiveness, focusing on risks to the community, workers, and the environment during the cleanup, including the length of such exposures;
- Implementability, meaning the technical and administrative feasibility of implementing the alternative, as well as the availability of off-site treatment, storage, and disposal sites;
- Cost, including capital costs, annual operation and maintenance, and net present value of capital;
- State acceptance, including state's preferred alternative and state ARARs; and
- Community acceptance, including determination of community concerns with alternatives and preferences.

5.3 Comprehensive List of Data Requirements:

The following is a list of comprehensive data requirements for use in analysis of further technologies. It also contains values of known parameters to aide in the evaluation of the remaining technologies. Analysis of some of the parameters has already been initiated through this study with the University of Maryland Cooperative Extension Service; they are labeled with the term "awaiting data", as results have not yet been received.

Table 5.2 Soil Data Needs.

Type	See Figures 3.5 and 3.6
pH	4.5 to 7.4
Groundwater flow	Requires quantification
Depth to water table	Requires quantification
Moisture content	Awaiting data
Hydraulic conductivity	Requires quantification
Organic content	Awaiting data
Cyanide content	Low
Sulfide or sulfate content	Requires quantification
Fluoride content	Requires quantification
Humic acid content	Requires quantification
Phenol content	Low
Oil and grease content	Low
Oxidizing agent content (nitrates, chlorates, perchlorates)	Present; awaiting data
VOC content	Low
SVOC content	Low
Chelating agents presence	Requires quantification
Silica and alkali content	Requires quantification
Na ₂ O and K ₂ O presence	126 to 450+ lb/A K ₂ O
Combustible liquid content	Low
Combustible solid content and depth	Low
Thermally unstable materials presence	Low
Cation Exchange Capacity	Awaiting data
Salinity	Awaiting data
Particle sizes and sieve analysis	Sandy and silty (see Figures 3.5 and 3.6) Awaiting data (mechanical analysis)
Density	Awaiting data
Magnesium Content	228 to 299 lb/A
Phosphate content	27 to 225 lb/A
Specific gravity	Awaiting data

Table 5.3 Lead Data Needs.

Levels of contamination	See Figure 3.1
Amount of contamination in each particle size range	Requires quantification
Extent of contamination	Requires quantification
Depth of contamination	Requires quantification
Forms of lead contamination in soil; are they species that form ions in solution?	Requires quantification
Nature of contamination: <ul style="list-style-type: none">• In the form of discrete particles?• Limited to a specific particle size range?• Adsorbed onto soil particles?	Requires quantification
Other contaminants in soil	None known or suspected
Solubility of lead in water	insoluble
Specific gravity of lead	11.35 at 20 degrees C

5.4 Additional Studies:

The level of lead above which the soil was considered contaminated was 400 ppm.

This was based on available ARARs. However, a more detailed risk analysis can be obtained using the EPA's Integrated Exposure Uptake Biokinetic Model (UBK). Should the Naval Academy not be satisfied with the 400 ppm standard, it is recommended that the UBK model be pursued.

SECTION 6: CONCLUSION

Greenbury Point requires remediation of lead contaminated soils to within the 400 mg/kg limit. Risks of lead are such that hazards to human health and the environment, especially children, must be avoided.

The contamination is most likely the result of past antenna preservation methods on the former Navy Radio Transmitting Facility. Lead based paint may have leached due to acid rain, flaked due to natural weathering, and chipped during removal operations. Soil testing indicates that contamination in the soil reaches limits as high as 11,000 mg/kg, but more data is necessary for adequate characterization of the site. The most important parameters required are depth and extent of contamination, existing lead compounds in the soil, and size of lead particles in the soil. A more thorough analysis of remediation options can then be conducted.

Although data is still required, only three alternatives require further analysis. They include: physical separation/concentration, soil washing, and cement-based solidification/stabilization. These three options are fairly well established, effective against lead, and appear to be compatible with site conditions at Greenbury Point. The other seven can be dropped from further study due to incompatibility with soil conditions, energy requirements, or degree of establishment of technology.

It is recommended that the Naval Academy use EPA's Integrated Exposure UBK model to determine a more site specific safe lead level should they not be satisfied with the 400 mg/kg limit. Data parameters listed in Section 5 should also be collected to confirm site

conditions and render a more exact description of nature and extent of lead contamination.

These parameters should be compared to ideal requirements for each of the three remaining technologies. The results of the subsequent analysis should then be combined with the results of this investigation to complete the Remedial Investigation/Feasibility Study portion of the CERCLA process. Finally, the document should be submitted to EPA for acceptance or modification and completion of the RI/FS process.

APPENDIX A DETAILED SITE INFORMATION

History:

Removal of lead from Greenbury Point is important from a historical perspective. As an area that has been settled since the 1600s, Greenbury Point is an historical landmark. The Point was part of what was once known as Broadneck Peninsula. Puritans settled this area in the seventeenth century after being driven out of Virginia over religious differences. The Peninsula was located on the western shore of the Chesapeake Bay from the present day Magothy River south to Anne Arundel County, and the portion on Greenbury Point was known as Providence. Appendix B contains a map of Providence obtained from files at USNA. The settlers earned their livings primarily by farming and trading tobacco. By 1676, Providence had faded because Annapolis had become the center of trade. The remainder of the Broadneck Peninsula then became farmland. Greenbury Point is located on property that was once owned by Ralph Williams, a merchant who at one time served as magistrate in Anne Arundel County during the Colonial Period.

Greenbury Point was later acquired by the Navy in 1909 for use as the U.S. Naval Academy Farm. It then was used as a Naval Air Facility in 1911 for six years. In 1918, very low frequency (VLF) transmitters were constructed to provide a communications link between the U.S. and Europe during World War I, and Greenbury Point was commissioned as the U.S. Naval Radio Station, Annapolis. In the 1940's, the VLF transmitters were modernized, and low frequency (LF) transmission capability was added to serve the strategic and tactical naval submarine forces in the Atlantic and Mediterranean areas. It was at this

time that the Station was named the Naval Radio Transmitting Facility (NRTF) which operated under the Naval Computer and Telecommunications Area Master Station, Atlantic in Norfolk, Virginia. In 1993, Congress approved the Base Realignment and Closure Commission's (BRAC's) recommendation that NRTF be disestablished because geographic coverage was also being provided by transmitter facilities in Cutler, Maine and Puerto Rico. The property was turned over to the U.S. Naval Academy in 1994, and NRTF is proceeding with closure while remaining a tenant on USNA land. Communications ceased in January of 1996, and four of the previous eighty employees remain; NRTF is mandated to be closed by the year 2000. Since the property was turned over to USNA, the Naval Academy has maintained Greenbury Point as a conservation area.

Archeology:

Several archeological sites have been identified on Greenbury Point, and even more are suspected, according to Al Luchenbach, the Anne Arundel County Archeologist. The sites include one prehistoric site and four historic sites. A Seventeenth century homestead, known as the Towne Neck Site, was discovered in 1993 when the cellar and foundation of a house as well as numerous artifacts were discovered. The site is considered eligible for listing on the National Register for Historic Places by virtue of the British colonial characteristics the site typifies and the data the site can present. Historic components on Greenbury Point include an early eighteenth century tavern, a late seventeenth century brick kiln, and a seventeenth century native American camp site.

Natural Resources:

Greenbury Point is rich in natural resources which may be affected by lead contamination. In addition, the Navy's plans to showcase these resources commands the removal of lead from the soil. Greenbury Point houses an abundance of plants, wildlife, wetlands, threatened and endangered species, and is surrounded by water resources which must be preserved.

Plants:

The 231 acres of Greenbury Point is covered with primarily open fields with shrubs; thick/dense scrub-shrub vegetation; forests; wetlands; and some developed areas. The open fields with shrubs and thick/dense scrub-shrub vegetation which cover most of Greenbury Point are located on the central part of the Point. Some of the open fields are maintained by periodic mowing and agricultural outlease agreements. The dominant herbaceous species include Queen Anne's lace, little bluestem, common plaitain, horsetweed, bush clover, aster, and goldenrod. The shrub areas consist of woody species, including choke cherry, staghorn sumac, mulberry, black raspberry, red raspberry, blackberry, persimmon, red cedar, blueberry, and dogwood.

The forests are located mainly near the shoreline of the Point, and the forest canopy is approximately fifty feet high.. Because they are exposed to the high winds of the Chesapeake Bay, they are considered to have "poor form." The dominant species include black locust, black cherry, white oak, chestnut oak, and pin oak. The understory also includes sassafras, white ash, and flowering dogwood. A thick layer of vines also exists in

the underbrush, including Japanese honeysuckle, greenbriar, Virginia creeper, and various berries.

Greenbury Point also contains some developed areas. In addition to the sixteen antenna towers which are located on the Point, several roads, buildings, and housing exist. The grassy areas around the developed areas are mowed regularly and include herbaceous species such as cinquefoil, clover, panic grass, Bermuda grass, and dandelion. Some oak, maple, and dogwood trees also exist around the buildings and along the roads.

Wetlands:

Wetlands on Greenbury Point are located primarily around the shoreline. They include both tidal and non-tidal areas with marsh communities as well as coastal/beach and open water areas. Wetlands connected to the Bay are brackish, but freshwater wetlands exist on Greenbury Point as well. The most common are the marsh or emergent scrub/shrub wetlands. They are densely vegetated with common reed grass, or *phragmites communis*. Other herbaceous species in these wetlands include cattail, smartweed, sedges, rushes, and jewelweed. Common shrubs include marsh elder, waxmyrtle, and buttonbush. Coastal wetlands border the Chesapeake Bay and the Severn River. They are located on the beaches and shallow open water areas. Most of the shoreline is protected from erosion by bulkheads or riprap, which along with the high energy wave action of the bay and river prevent much vegetation from growing. However, when the tide recedes, the shallow open water areas are exposed.

Wildlife:

Greenbury Point attracts and supports a variety of wildlife species. The open field and shrub areas house songbirds and small mammals. The berry producing shrubs provide summer food for upland gamebirds, song birds, and a variety of small mammals. The twigs and foliage of the shrubs support deer, skunk, squirrel, and rabbit. Cover for nesting wildlife from the winter elements as well as predators is provided by the dense thickets of the shrubs. Hawk species thrive on the many small mammals and roosting perches provided by the towers. There are sixteen pairs of osprey on Greenbury Point which use utilize the towers from March to September. Appendix C contains photographs of the nesting osprey. Migrating monarch butterflies also use the southern tip of Greenbury Point during October. Birds found in the open field and shrub areas include the bobwhite quail, red-tailed hawk, osprey, catbird, cardinal, orchard oriole, eastern kingbird, blue jay, common yellowthroat, and field sparrow. Other common wildlife include the red fox, white-tailed deer, striped skunk, gray squirrel, raccoon, eastern cottontail, meadow vole, white-footed mouse, black rat snake, and northern cricket frog.

Forests of Greenbury Point also support various species, though they are small in size with little area to travel between stands. The abundant oak tree acorns provide food year round for several species. The black cherry fruits support the songbirds and small mammals. Mammals and cavity nesting birds alike benefit from the habitat provided by the forests. The forests also provide cover and shelter for large mammals, especially during the winter months. Species found in the Greenbury Point forests include the wild turkey, common flicker, red-bellied woodpecker, tufted titmouse, scarlet tanager, red-eyed virio, red fox,

opossum, masked shrew, five-lined skink, northern copperhead, red-backed salamander, and wood frog.

Wetland areas also provide excellent habitat and food for various wildlife species. The shallow, open water of the Chesapeake Bay and the Severn River attract hundreds of migratory waterfowl in the winter and provide fish for osprey, herons, and gulls. The vegetation in the freshwater wetlands is consumed by waterfowl, muskrat, and numerous songbirds. Because the vegetation is thick and dense in the wetland, it also provides ideal cover, shelter, and nesting habitat.

Diverse species are found in the narrow beach areas and the low tidal mudflats which comprise the shoreline of Greenbury Point. Many feed off of the grasses and shrubs in the scrub/shrub wetlands, while the macroinvertebrates found in the shallow mudflats an ideal food source for shorebirds. Bird species found in the wetlands include the osprey, mallard, black duck, great blue heron, ring-billed gull, fish crow, red-winged blackbird, and song sparrow. Waterfowl that visit Greenbury Point during the winter include canvasback ducks, buffleheads, and common goldeneye. Other wildlife include the muskrat, raccoon, long-tailed weasel, star-nosed mole, eastern painted turtle, rough green snake, red spotted newt, and bullfrog.

Threatened and Endangered Species:

According to the U.S. Fish and Wildlife Service, there are no known occurrences of federally listed species on Greenbury Point. The Maryland Department of Natural resources also documents that there are no state listed species, either. However, an Historic Waterfowl Staging and Concentration Area is located off the shore of Greenbury Point. The locations

for these areas are determined from data collected over several years on species which utilize the areas over the winter. These areas are protected under Maryland's Chesapeake Bay Critical Area Program. Furthermore, two listed species were identified in the Greenbury Point area in the Christmas Bird Count conducted by the Maryland Ornithological Society on December 31, 1995. The Peregrine Falcon, which is a state endangered species, and the dark-eyed junco, which is in need of conservation in Maryland were found. In addition, four other birds found during the survey are identified on the Nature Conservancy's global and state ranking system. Although they are not protected by the state, they are tracked for decision making purposes. The four birds include the sharp-shinned hawk, the northern harrier, the golden-crowned kinglet, and the red-breasted nuthatch.

Chesapeake Bay:

The Chesapeake Bay offers a variety of aquatic resources associated with Greenbury Point. The Point is surrounded by a shoal that extends 800 feet east and 250 feet west of the peninsula. Because it is less than ten feet below the surface of the water, it is an ideal site for forage fish species. this species includes bay anchovies, killfish, silversides, sheepshead minnow, atlantic menhaden, alewife, and blueback herring. Where the shoal drops off to deeper water, a diverse community of predatory fish species can be found, including striped bass, yellow perch, and weakfish. Shellfish found in the vicinity of Greenbury Point include eastern oyster, soft shell clam, and blue crab.

Present and Future Use of the Site:

Because boat launching, fishing, picnicking, camping, bird watching, hiking, and educational tours are allowed on Greenbury Point, the need for cleanup of the lead

contamination may be even more pronounced. Greenbury Point is frequently used by community groups, midshipmen, children, and watermen. As the last major undeveloped tract of land in Anne Arundel County, many community groups and individuals utilize the Point for environmental appreciation purposes. Private groups include the Severn River Association, the Burley Creek Community Association, the Providence Community, the Chesapeake Bay Foundation, the Alliance for Community Education, and the Anne Arundel Bird Club. Senator Paul Sarbanes, Senator Gerald Winegrad, and Ms. Elsie Munsell, Deputy Assistant Secretary of the Navy (Environment and Safety), are just a few of the political figures who have visited Greenbury Point. Federal agencies, such as the Chesapeake Bay Program Office, have guided tours around the Point, and countless sailors and watermen have stopped off along its shores.

Many students use Greenbury Point for environmental projects. Midshipmen and students from other colleges alike are frequently seen on the Point. Students from Anne Arundel Community College helped construct seasonal waterfowl impoundments, and the college continues to manage them to remove nutrients and sediment from the stormwater. Students from the college also manage the phragmites control program and are working on the installation of an offshore breakwater. Midshipmen also satisfy some of their community service requirements on Greenbury Point. They completed an oyster bar reseeding project, cleaned up the shores, and have planted various flower gardens and hundreds of trees. Children use Greenbury Point for regular nature walks and camps. They participate in stormwater runoff demonstrations, nature games and walks, recycling

activities, wildlife habitat projects, erecting purple martin houses and blue bird boxes, and planting sunflower seeds.

USNA also plans to build an education center on the Point. They plan to use one of the existing buildings on Greenbury Point as a center where exhibits of history, archeology, and natural resources of the Point can be displayed. The project will be completed in cooperation with Anne Arundel Community College. A nature trail, boardwalk, and observation deck to observe waterfowl is planned as well. The Center will allow midshipmen, military personnel, and school children the opportunity to observe favorable land stewardship, watch local habitat, and assist with projects for the betterment of themselves and Greenbury Point. Others will be allowed through scheduled visits as well. The education center will undoubtedly increase the number of people visiting Greenbury Point to an even higher number than today.

APPENDIX B

LEAD BACKGROUND

Uses of Lead:

The prevalent use of lead in paints, gasoline additives, and other products has resulted in wide dispersion throughout the environment. This "dispersion throughout the environment" can be termed "lead contamination", and many sources for the contamination exist. Sources of lead contamination include:

- lead acid battery breaking activities;
- primary and secondary lead smelting and refining;
- production of lead acid batteries;
- production, storage, and distribution of gasoline with leaded additives;
- solder use and manufacture;
- plumbing; ceramics and crystal manufacture;
- paints for houses, bridges, ships, and other structures;
- paint abrasive blasting material;
- wire manufacture and coating;
- automobile demolition; construction demolition, especially activities involving plumbing and paints;
- production and use of fishing sinkers;
- pesticide production and use;
- cathode-ray tube production and use;
- rifle ranges and munition dumps, including state game land and military ranges;
- ammunition and explosive manufacturing;
- sewage sludge;
- by-products from metal production, such as electric arc furnace dust from steel production;
- radioactive shielding from x-ray machines to reactors;
- other metals mining, smelting, and alloying, such as for copper, zinc, cadmium, and chromium.

Transport of Lead:

Lead enters the air, water, and soil through the variety of human activities previously mentioned. Lead in the atmosphere is present predominantly in the particulate form. After

being released into the atmosphere, the particles disperse and are ultimately removed by wet or dry deposition. The majority of the lead particles settle through wet deposition, or precipitation. Particles of size greater than 2 μm settle out of the atmosphere fairly rapidly and reside fairly close to the emissions source, while smaller particles can settle thousands of miles away. Lead has been found in sediment cores of lakes in places far removed from any point sources of lead release. Lead, in comparison with other metals, is removed from the atmosphere by wet deposition fairly quickly. Metals such as Fe, Al, Mn, Cu, Zn, and Cd take much longer to settle than lead.

Lead Contamination:

The majority of lead's contamination occurs in soils. The Environmental Protection Agency (EPA) has estimated that there are over 3,000 sites across the United States contaminated with lead. Its widespread use is responsible for its status as one of the most common contaminants at sites listed on the National Priorities List. While the EPA has set acceptable lead levels in soils at below 400 ppm, contaminated sites and even many urban environments contain levels several times the acceptable level. Of 436 Superfund Sites surveyed in a study conducted in 1992, lead contamination ranged from 0.16 and 366,000 mg/kg, or ppm; soils considered uncontaminated typically contain approximately 2 to 200 ppm. While a normal background concentration of lead in the soil is approximately 15 mg/kg, lead has been detected in soils in urban environments at concentrations of up to 15,000 mg/kg, primarily from automobile exhaust, lead paints, and batteries (Page and Chang, 1993). Lead is commonly found at battery breaker sites in concentrations up to

100,000 mg/kg; lead smelters in concentrations of up to 51,000 mg/kg; and at gun clubs in concentrations of up to 10,000 mg/kg (Paff and Bosilovich, 1995).

APPENDIX C

REASONING FOR IDEAL PARAMETERS FOR REMEDIATION TECHNOLOGIES

Ideal Parameters for Soil Flushing.

Parameter	Limits	Reason
Hydraulic Conductivity	$>10^{-3}$ cm/sec; low clay content	Good conductivity allows efficient delivery of flushing fluids
Contaminant Solubility in Water	$>1,000$ mg/L	Soluble compounds can be removed by water flushing
Complexity of Waste Mixture	Less is beneficial	Complex mixture increases difficulty in formulation of a suitable extraction fluid
Spacial Variation in Waste Composition	Less is beneficial	Changes in waste composition may require reformulation of extraction fluid
Flushing Fluid Characteristics	Low toxicity, low cost, and allow for treatment and reuse;	Toxicity increases health risks and increases regulatory compliance costs
	Should not plug or have other adverse effects in the soil;	Expensive or nonreusable fluid increases costs
	Low viscosity	Lower viscosity fluids flow through soil more easily
Cyanides, Sulfides, and Fluorides	Low is preferred	Potential for generating fumes exists
Specific Surface Area of Matrix	<0.1 m ² /g	High surface area increases sorption on soil
Cation Exchange Capacity (CEC)	$<$ about 50 to 100 meq/kg	High CEC indicates matrix has high affinity for metal sorption
Humic Acid Content	Low is preferred	Humic content increases sorption

Ideal Parameters for Electrokinetic Treatment.

Parameter	Limits	Reason
Hydraulic Conductivity	Preferably low	Technology applicable in zones of low hydraulic conductivity, particularly with high clay content
Depth to Water Table	Saturated	Technology applicable in saturated soils
Areal Extent of Contamination	Well defined	To assess electrode and recovery well placement
Electroosmotic Permeability	Well understood	To estimate the rate of contaminant and water flow that can be induced
Cation Exchange Capacity (CEC)	Low	Technology most efficient when CEC is low
Metals Analysis	Well defined	Technology applicable to acid soluble polar compounds, but not to nonpolar organics and acid insoluble metals
Salinity	Low	Technology most efficient when salinity is low

Ideal Parameters for Physical Separation/Concentration.

Parameter	Limits	Reason
Particle Size	See Table 4.5	Separation improves with higher particle sizes. Ultrafines and silts undesirable for gravity separation.
Contaminant Metal Concentration (in each size class)	Higher concentration in specific size classes favorable.	Makes size separation worthwhile
Concentration Criteria	cc > 2.5 favorable cc > 1.25 acceptable	The larger the density difference between metal and soil, the better the separation.
Moisture Content	Low moisture favorable for dry separations; high moisture favorable for wet separations.	High moisture content can interfere with dry processing such as dry screening.
Particle shape	Variable	Round particles can roll off shaking table; flat particles may not move on table; elongated particles could pass through screens.
Waste complexity	Fewer types of metals preferred	Multimetals complicate separation unless all metals in same separation fractions.
Spacial Variation	Homogeneous preferred	Variations in waste composition may reduce removal efficiency
Magnetic Properties	Ferromagnetism	Ferromagnetic fraction can be separated from nonmagnetic fraction.
Floatability	Hydrophobic surface	Helps air bubbles attach to. particle surface in froth flotation.

Ideal Parameters for Pyrometallurgical Separation.

Parameter	Limits	Reason
Waste Volume	Large quantity of material	Pyrometallurgical processing typically works best with continuous feed.
Particle Size	Uniform; no clumps, no silts	Heat transfer efficiency
Moisture Content	No free moisture	Presence of water increases energy requirements.
Metal Content	Concentration of metal levels should typically be in the percent range.	Percentage concentrations are required to make process feasible; lower concentrations typically processed by hydrometallurgical methods.
Thermal Conductivity of Waste	Higher is preferred.	Treatment requires the ability to transfer heat into the waste matrix.

Ideal Parameters for Soil Washing.

Parameter	Limits	Reason
Particle-Size Distribution	> 2 mm 0.25-2 mm 0.063-0.25 mm <0.063 mm	Oversize pretreatment requirements Effective soil washing Limited soil washing Difficult soil washing, though up to 20% clay may be tolerable
Clay Content	Low is preferred	High clay content makes soil washing difficult.
Type and Size of Debris	None is preferred	Presence of debris increases pretreatment requirements.
Complexity of Waste Mixture	Less is beneficial	Increases difficulty in formulation of a suitable extraction fluid.
Waste Composition Variation	Homogeneous material preferred	Variation in feed composition complicates processing.
Waste Buffering Capacity and pH	Low is preferred with acid extraction	High buffering capacity or pH increases acid consumption
Cyanides, Sulfides, and Fluorides	Low is preferred	Potential for generating fumes at low pH
Cation Exchange Capacity (CEC)	≈ 50-100 meq/kg	High CEC indicates metal has high affinity for metal sorption.
Humic Acid Content	Low is preferred	Humic content increases sorption.
Extraction Fluid Characteristics	Low toxicity, low cost, and allow for economic treatment and reuse	Toxicity increases health risks and regulatory compliance costs; expensive or nonreusable fluid increases costs.
Equilibrium Partitioning of Contaminant Between Matrix and Extraction Fluid	> 1,000 mg/L metal in extractant desired	Low partitioning of contaminant into the extraction fluid increases fluid volumes required to attain cleanup goal.
Contaminant Solubility in Water	> 1,000 mg/L	Soluble compounds can be removed by water flushing.

Ideal Parameters for Polymer Microencapsulation Solidification/Stabilization.

Parameter	Limits	Reason
Water Content	Dry solid feed	High water content causes treated product to be too fluid
Oxidizing agents, such as nitrates, chlorates, and perchlorates	Low presence	Organic binder is a potential fuel source and may react with oxidizers
Organic Solvents	Low presence (particularly aromatic solvents)	Can dissolve the binder
Oils, Greases, and Chelating Agents	Low presence	Will dissolve and migrate through the binder
Thermally Unstable Materials	As thermally stable as the binder	Hydrated salts may decompose during hot mixing with the binder, thus liberating vapor and causing poor binding.

Ideal Parameters for Cement-Based Solidification/Stabilization.

Parameter	Limits	Reason
Organic Content	<20-45% by wt	Organic materials can interfere with bonding
VOC Content	<50 ppb	VOCs can vaporize during curing process; organic materials can interfere with bonding
SVOC Content	organics < 10,000 ppm	Organic materials can interfere with bonding
Oil and Grease Content	<10% by wt	Oil and grease coat the waste particles and weaken the bond between waste solids and cement
Phenol Content	<5%	Phenols can reduce compressive strength of product
Particle Size	Limited amt of insoluble particulate passing through a 200 mesh screen	Fine particulate can coat the waste particles and weaken the bond between waste solids and cement.
Cyanide Content	<3,000 mg/kg	Cyanides interfere with bonding of waste materials
Sulfate Content	<1500 ppm for Type I Portland cement or use cement formulated to tolerate higher sulfate levels	Can cause cement to spall after curing

Ideal Parameters for In-Situ Vitrification.

Parameter	Limits	Reason
Soil Composition	> 30% SiO ₂ > 1.4% Na ₂ O + K ₂ O on a dry weight basis	Required to form melt and cool to stable treated waste form
Contaminant Depth	> 6 ft < 20 ft	Uncontaminated overburden helps retain volatile metals; as batch process, economics improve with increased thickness of contaminated volume; treatment demonstrated to 20 ft.
Combustible Liquids	<1 to 7% depending on the BTU content of the organic	Heat removal capacity of the off-gas treatment system
Combustible Solids	< 3,200 kg/meter depth and > 30% soil	Can generate excessive off-gas volumes on combustion
Groundwater	Groundwater control required if contamination is below the water table and soil hydraulic conductivity is > 10 ⁻⁴ cm/sec	Water inflow increases energy required to vaporize water.
In-Situ Voids	Void volume < 150 ft ³	Can generate excessive off-gas
Sealed Containers	None present	Containers can rupture during heating resulting in a large pulse of off-gas generation.
Underground Structures and Utilities	> 20 ft from melt zone	Items closer than 20 ft must be protected from heat.
Surface Slope	< 5%	Melt may flow under influence of gravity.

Ideal Parameters for Ex-Situ Vitrification.

Parameter	Limits	Reason
Silica and Alkali Content	> 30% SiO ₂ > 1.4% alkali on dry weight basis	Required to form melt and cool to stable treated waste form; can be adjusted by frit addition
Particle Size	Small preferred, depending on technology	Small particle size ensures melt homogeneity.
Moisture Content	< 25% water by weight	Energy input required to vaporize water.
Waste Organic Content	< 10%	Increases off-gas volume
Power Availability	Adequate supply available	Vitrification requires significant energy input.

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